NAVIGANT

RES 1 Baseline Load Shape Study

Heating Season Short Report

Prepared for:

The Electric and Gas Program Administrators of Massachusetts
Part of the Residential Evaluation Program Area

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EXECUTIVE SUMMARY

This report documents the load shapes, winter peak demand levels and winter energy consumption for all major end uses,[1] metered at approximately 350 homes representative of the Massachusetts statewide population during the winter of 2017/2018. The results are derived from the ongoing residential baseline end use load research study Navigant is conducting on behalf of the Massachusetts Program Administrators (PAs) and Energy Efficiency Advisory Council (EEAC), and are designed to assist the PAs and EEAC in crafting and evaluating program offerings targeted to reduce residential peak demands now and in the future. Study highlights include:

Conclusion 1: Based on initial analysis of lighting data, lighting is likely the end use with the largest contribution to total winter consumption and winter peak.

Conclusion 2: Based on Conclusion 1 above, further improvements in the installed lighting efficiency and controls, either induced by programs or the overall market, will cause significant reductions in peak loads.

Depending on the discount rate assumed and the final results of the potential studies currently being conducted by the PAs, there may remain significant opportunities for programs to cost-effectively reduce energy and peak consumption by inducing the early retirement of incandescent lamps and installation of lighting controls. Particularly where individuals are waiting for infrequently-used lamps to burn out before replacing them, there are significant lifetime savings available in replacing them early. Similarly, networked/connected LEDs offer additional energy and load shifting potential.

Conclusion 3: Electric resistance heat has a surprisingly flat hourly load shape on peak days, more similar to a refrigerator than an air conditioner on a peak day.

Conclusion 4: Electric resistance heating consumption is highly variable. The top 25% of households with electric resistance heat presently consume approximately ten times as much as the median.

Based on conclusions 3 and 4, it may be difficult to generate HVAC peak demand or energy savings with program interventions. Targeting high users would help increase savings by a large amount. A bill-based electric resistance heating targeting algorithm could be developed and tested using this data.

Conclusion 5: Electric water heaters offer a significant opportunity for winter peak demand savings, the largest non-HVAC opportunity.

If the PAs are looking for opportunities to reduce winter peak demand, they should consider electric water heater demand response opportunities and heat pump water heater upgrades in homes with non-electric heat.

[1] Lighting was not directly metered as part of this study and is therefore not presented. However, one can deduce – based on whole house loads and other end-uses that are metered directly – that lighting represents the largest winter electric load.

1. INTRODUCTION

Navigant is currently conducting a large multiyear baseline saturation and load shape study in which data is collected via online survey, onsite validation, and long-term metering. This study strives to provide the Massachusetts Program Administrators (PAs) and Energy Efficiency Advisory Council (EEAC) consultants more granular data about the energy consumption of residential buildings and their occupants, and learn more about relevant opportunities for reducing overall consumption and consumption during peak periods. The study began in January 2017 and will continue through at least the spring of 2019.[2]

1.1 Study Goals

The primary goal of the baseline study is to collect saturation, penetration, and usage behavior data for all major electric and gas appliances, mechanical equipment, and electronics in Massachusetts homes. These data will support energy and peak demand savings calculations for program evaluation and design, and provide additional insight into the savings potential in the existing residential buildings market. The secondary goal of this study is to support other research that the PAs are undertaking by providing comprehensive data for the sampled customers. These include energy efficiency potential studies and market effects research, among others.

This report is intended to answer the primary research question stated in the study's Stage 3 Plan: "How and when are people using the electric equipment in their homes?" by presenting key findings from the metered data relevant to the heating season.[3] The data contained and referred to in this report was collected between October 2017 and March 2018. The results and findings provided here may change in future updates to this report based on newly available or updated information.

1.2 Summary of Research Activities

To answer the primary research question of "How and when are people using the electric equipment in their homes?", the research team followed the high level step-by-step process outlined in Figure 1. Information for each step is provided below, and additional details on the study's methodology is contained in Appendix A.

Figure 1. Study Approach for Determining End Use Load Shapes

[2] The originally scoped study was intended to last until the spring of 2018. However, the program administrators (PAs) and Energy Efficiency Advisory Council (EEAC) have decided to extend the study for at least 1 additional year. The Stage 3 Plan for the additional year of the study (Phase 3) has been finalized as of February 2018.

[3] This study has two primary research questions and three secondary research questions. All research questions can be found in the study's Stage 3 Plan.

1. **Conduct online survey** to inventory saturation of several key end uses in Massachusetts residences, which serves as the population frame for the metered sample. The survey asked questions related to the respondents' demographics, home characteristics, and home appliances. Survey recruitment was completed via mailed postcards; most of the postcards were sent to households sampled randomly from the participating statewide utilities' customer bases. The last 1,600 completes were obtained as part of a targeted recruitment effort based on geographies that had a higher saturation of underrepresented priority characteristics, such as renter, low income, multifamily, and non-English speaking households. The research team received 6,901 total survey completes, including 228 Cape Light Compact (CLC) oversample completes, between February and June 2017.
2. **Draw onsite sample** to meet end use confidence and precision targets determined during the project's planning phase. The core sample was drawn to maintain several representativeness quotas. The oversample includes homes with specific under-sampled end uses which ensures that all end uses meet the confidence and precision targets.
3. **Install meters** to measure all end uses at core sampled homes and the sampled end use for oversampled homes. Two kinds of meters were installed: meters installed in the panel which communicate remotely via powerline carrier, and non-communicating plug load meters installed at the end use. The initial 300 core site visits and 56 oversample site visits were completed between March and June 2017. The team downloaded the data from plug load meters for the heating season during revisits conducted in February and March 2018. The meters will be installed for at least one more year.
4. **Analyze metered data** to determine typical year and peak year load shapes by end use.[4] Data from all meters were rigorously checked for quality and completeness before being aggregated to hourly granularity at each site. Site-level data was aggregated to generate per-home average load shapes and peak period consumption for each end use. Saturations from survey data were used in conjunction with site-level metered data to generate aggregate (statewide) average load shapes and peak period results.

Table 1 shows the measured end uses for which Navigant is providing heating season load shape results in this report. Most end uses on this list were identified during study planning as high priority end uses to measure. The end uses in the table marked with an asterisk (*) were those that the team had enough metered data to report on even though they were not identified as high priority end uses. End uses that proved to be inconsequential to the overall load due to either small sample size or small load are combined as other heating and cooling,[5] other pumps,[6] and other miscellaneous metered loads.[7] Unmetered loads were calculated by subtracting all of the metered loads from the metered whole premise loads. While lighting is not explicitly addressed in this report or the accompanying Appendices, the load attributable to lighting is included in the unmetered loads.[8]

[4] This report presents non-weather normalized results. Typical and peak year load shapes will need further weather normalization. Annual weather normalized results will be presented in the next report, which will be delivered in May/June 2018.
[5] All cooling-only end uses (room air conditioners, central air conditioners, ductless air conditioners), central heat pumps, whole house fans, and ground source heat pumps are combined as other heating and cooling.
[6] Pool pumps were the only type of pump found to have significant electricity consumption. All other pumps were combined into the other pumps group, which includes well pumps, booster pumps, sump pumps, and ejector pumps.
[7] The other miscellaneous metered loads group includes a long list of rare end uses that were metered but cannot be statistically extrapolated individually. These end uses include electric vehicle chargers, hot tubs, pool heaters, water beds, large battery chargers, and large fish tanks.
[8] Lighting is expected to be about half of the remaining useful load and will be disaggregated in the comprehensive report.

Table 1. Measured End Uses by Category

End Use Category	Measured End Uses	
Heating and Cooling	• Furnace fan • Hardwired electric heat • Plug-in electric heat	• Boiler distribution system • Ductless heat pump* • Other heating and cooling
Kitchen	• Dishwasher • Refrigerator	• Second refrigerator • Freezer
Hot Water	• Electric water heater • Heat pump water heater	• Gas water heater*
Laundry	• Electric clothes dryer • Gas clothes dryer*	• Electric washer
Miscellaneous	• Pool pumps • Other pumps • Primary TVs and peripherals*	• Dehumidifiers • Computers and peripherals* • Other miscellaneous metered loads

**End uses that the team had enough metered data to report on even though they were not identified as high priority end uses.*

1.3 Terminology

Throughout this report, the research results are referenced with various terminology, including:

- **Population:** These results are scaled by saturation and show the overall impact to the system on average by home, but do not represent the impact from an individual appliance.
- **For Homes with End Use:** These results only include homes with the relevant end use installed, irrespective of the saturation of that end use in the population.
- **Winter:** To calculate winter-only results, the team has used the metered data from November 1, 2017 to March 31, 2018. This reflects the portion of the prime heating season that was available at the time of the report's publication. The May comprehensive report will include a full winter season and monthly and annual consumption estimates.
- **ISO-NE Peak:** For the purposes of this report, ISO-NE peak is approximated as 5-7 p.m. on the three non-holiday weekdays with the highest ISO-NE system peak loads in winter 2017/2018 (January 2nd, 3rd, 4th and 5th).[9]
- **Expanded Peak:** For the purposes of this report, the Expanded peak is approximated as 5-9 p.m. on the three days with the highest ISO-NE system peak loads in winter 2017/2018 (January 2nd, 3rd, 4th and 5th).
- **Peak Days:** These results include data only from the three days identified as peak days (January 2nd, 3rd, 4th and 5th).
- **Building Type:** Either Single-Family Detached, Single-Family Attached (2-4 units), or Multi-family (5+ units)
- **Number of Occupants:** number of permanent residents (adults and children) living in the home

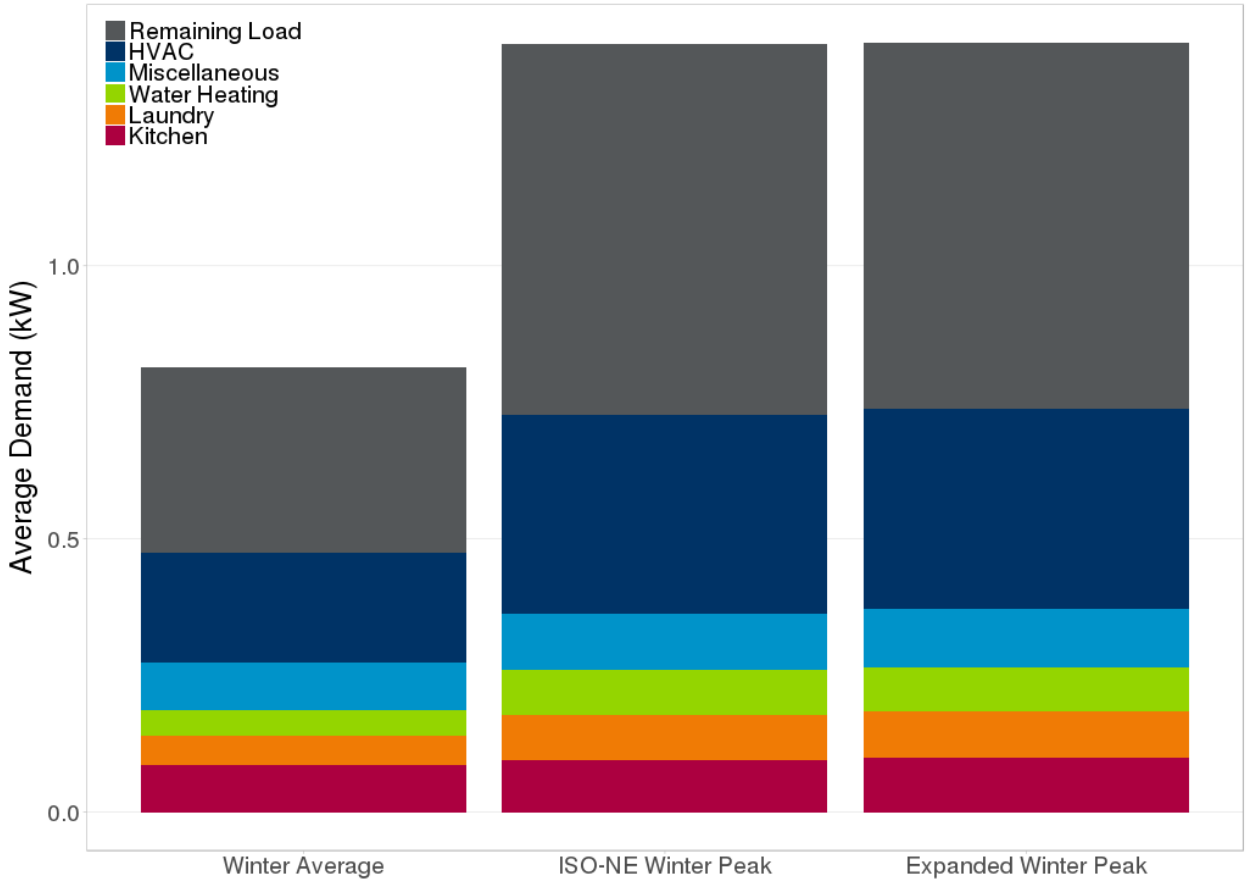
[9] ISO-NE load data for 2017/2018 can be retrieved at https://www.iso-ne.com/isoexpress/web/reports/load-and-demand/-/tree/dmnd-rt-hourly-sys

2. RESULTS AND KEY FINDINGS

This section contains the winter metering period energy consumption (expressed as average power), ISO-NE peak demand and extended peak findings by end use category in the first two subsections and further end use specific results in the third subsection. The average demand for all three time periods by end use category is shown in Figure 2. The full accompanying datasets, including additional charts and graphics, are provided as Appendix C to this report.

These results are not weather normalized and represent the total consumption over the 4.5-month winter metered period (November 1, 2017 through March 31, 2018). The team performed a preliminary building modeling analysis of a typical single family residential building model with weather data for Worcester, MA from 2005 through 2018 to compare seasonal data over the last several years. The preliminary analysis suggests that the 2017/2018 heating season was about average based on modeled heating energy consumption from the past 12 years. Therefore, when the heating season results are fully weather-normalized, the team expects that the consumption will not change appreciably.

Figure 2. Average Demand for Three Time Periods by End Use

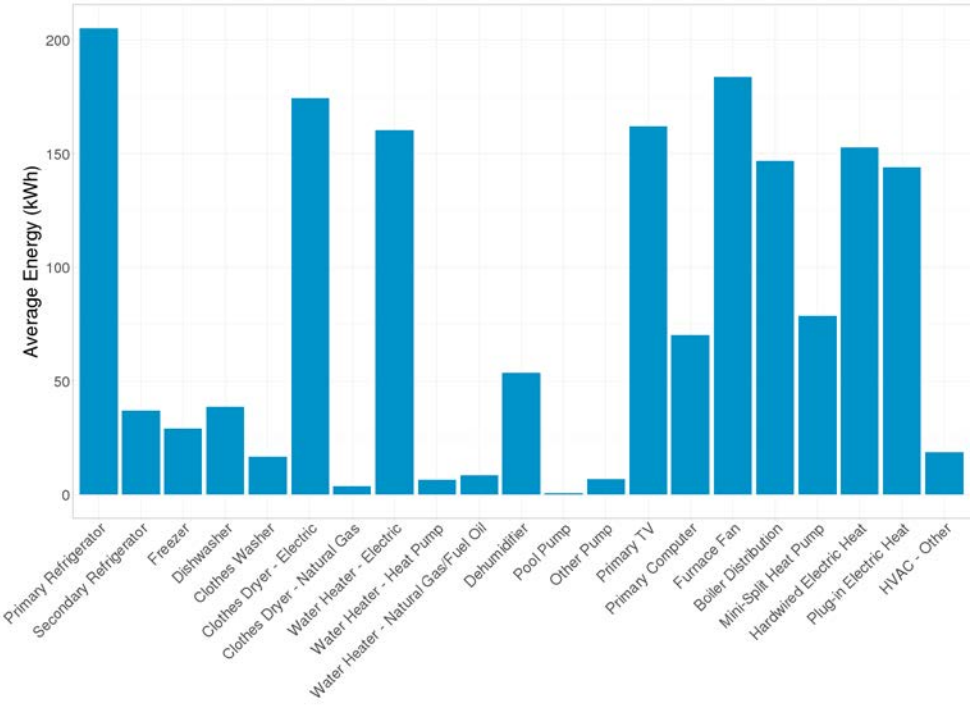


2.1 Energy Consumption

A wide variety of end uses contributes to overall energy consumption. The end use specific energy consumption values for the winter metering period (November 1, 2017 through March 31, 2018)[10] are shown in Table 2. The saturations listed in the first column of the table were collected as part of this study and delivered to the PAs on July 17, 2017.

The energy consumption of each end use across the population is shown in Figure 3. This report will draw attention to opportunities that the research team has identified in the areas with the highest energy consumption.

Figure 3. End Use Specific Energy Consumption for the Population by End Use (kWh)



Key Finding: *The top non-lighting contributors to heating season energy consumption across all homes in Massachusetts are primary refrigerators, furnace fans, electric clothes dryers, electric water heaters, primary TVs, and hardwired electric heat.*

The number of occupants and weekday occupancy are highly correlated with overall energy usage, as shown in Figure 4. Owner-occupied homes and single family detached homes also tend to have higher

[10] The comprehensive report to be delivered in May will include annual energy consumption estimates, while the numbers in this report include the portion of the heating season that was available at the time of publication.

energy use. Table 2 shows the energy consumption of individual metered end uses both for homes with the end use and averaged across the entire population of homes in Massachusetts.

Figure 4. Average Winter Energy Consumption by End Use Category and Building/Occupancy Demographics

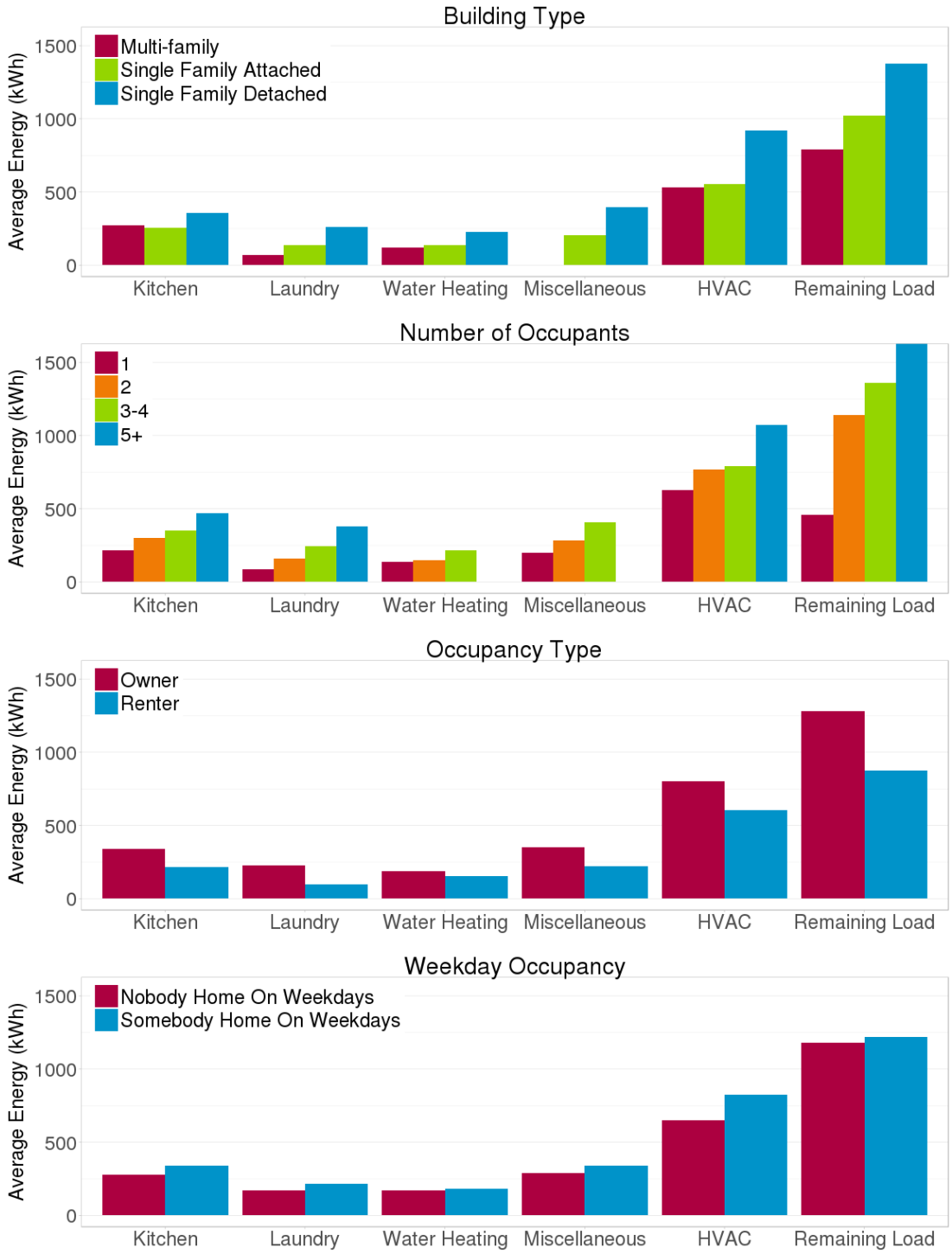


Table 2. Winter (December 1, 2017 through March 31, 2018) Energy Consumption by End Use

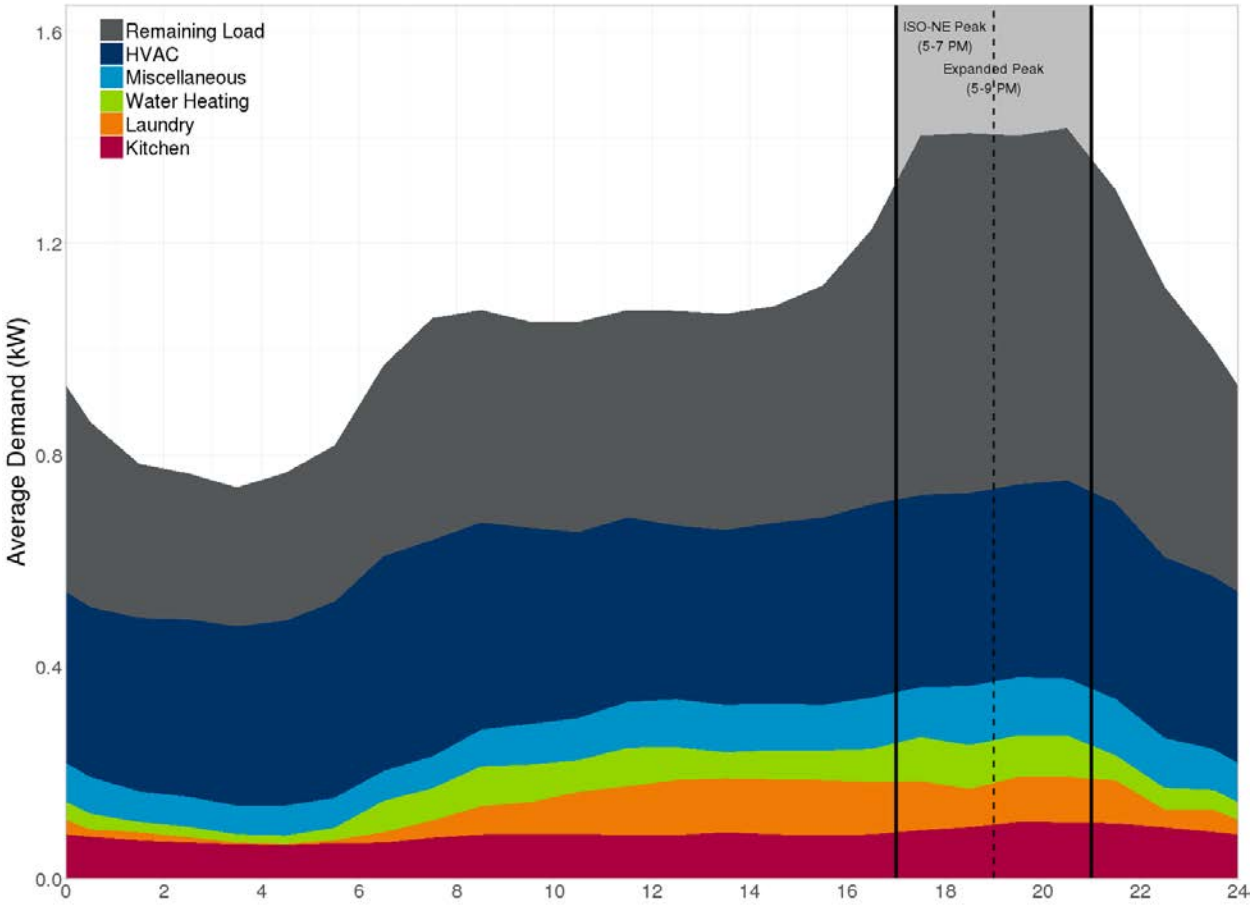
End Use Category	End Use	Saturation Across MA Homes [A]	Winter Energy Per Home with End Use (kWh) [B]	Population Winter Energy Per Home (kWh) [C = A x B]	Percent of Winter Energy Load (%) [C/∑C]
Heating, Cooling, and Ventilation	Furnace Fan	0.39	473	184	6%
	Hardwired Electric Heat	0.13	1160	153	5%
	Boiler Distribution	0.54	272	147	5%
	Space Heater or Plug-in Fireplace	0.40	364	144	5%
	Mini-Split Heat Pump	0.041	1900	79	3%
	HVAC - Other	N/A	N/A	19	1%
	HVAC Total	**N/A**	**N/A**	**725**	**25%**
Water Heating	Water Heater - Electric	0.14	1180	160	5%
	Water Heater - Natural Gas/Fuel Oil	0.4	21	8	< 0.5%
	Water Heater - Heat Pump	0.011	571	6	< 0.5%
	Water Heating Total	**N/A**	**N/A**	**175**	**6%**
Kitchen	Primary Refrigerator	0.99	207	205	7%
	Dishwasher	0.69	56	39	1%
	Secondary Refrigerators	0.28	134	37	1%
	Freezer	0.20	145	29	1%
	Kitchen Total	**N/A**	**N/A**	**310**	**11%**
Laundry	Clothes Dryer - Electric	0.53	332	174	6%
	Clothes Washer	0.73	23	17	1%
	Clothes Dryer - Natural Gas	0.21	18	4	< 0.5%
	Laundry Total	**N/A**	**N/A**	**195**	**7%**
Misc.	Primary TV	0.93	175	162	6%
	Primary Computer	0.76	93	70	2%

	Dehumidifier	0.35	151	54	2%
	Other Pump	N/A	N/A	7	< 0.5%
	Pool Pump	0.06	12	1	< 0.5%
	Misc. Metered	N/A	N/A	20	1%
	Misc. Total	**N/A**	**N/A**	**313**	**11%**
Remaining Load	Unknown	N/A	N/A	1,235	42%
All	**Total All End Uses**	**N/A**	**N/A**	**2,953**	**100%**

2.2 Peak Demand

The end use peak day load shapes by category with both peak periods highlighted are shown in Figure 5, which illustrates that both winter peak demand values are driven primarily by HVAC loads and loads not individually metered in this study. Based on early analysis of the Northeast Lighting Study results, lighting is expected to be 50-75% of the remaining load during peak.[11] The end use specific average peak demand values for the winter metering period (November 1, 2017 – March 31, 2018) are shown in Table 3. The saturations listed in the first column of Table 3 were collected as part of this study and delivered to the PAs on July 17, 2017.

Figure 5. Winter Peak Day End Use Category Load Shapes with Peak Periods Highlighted

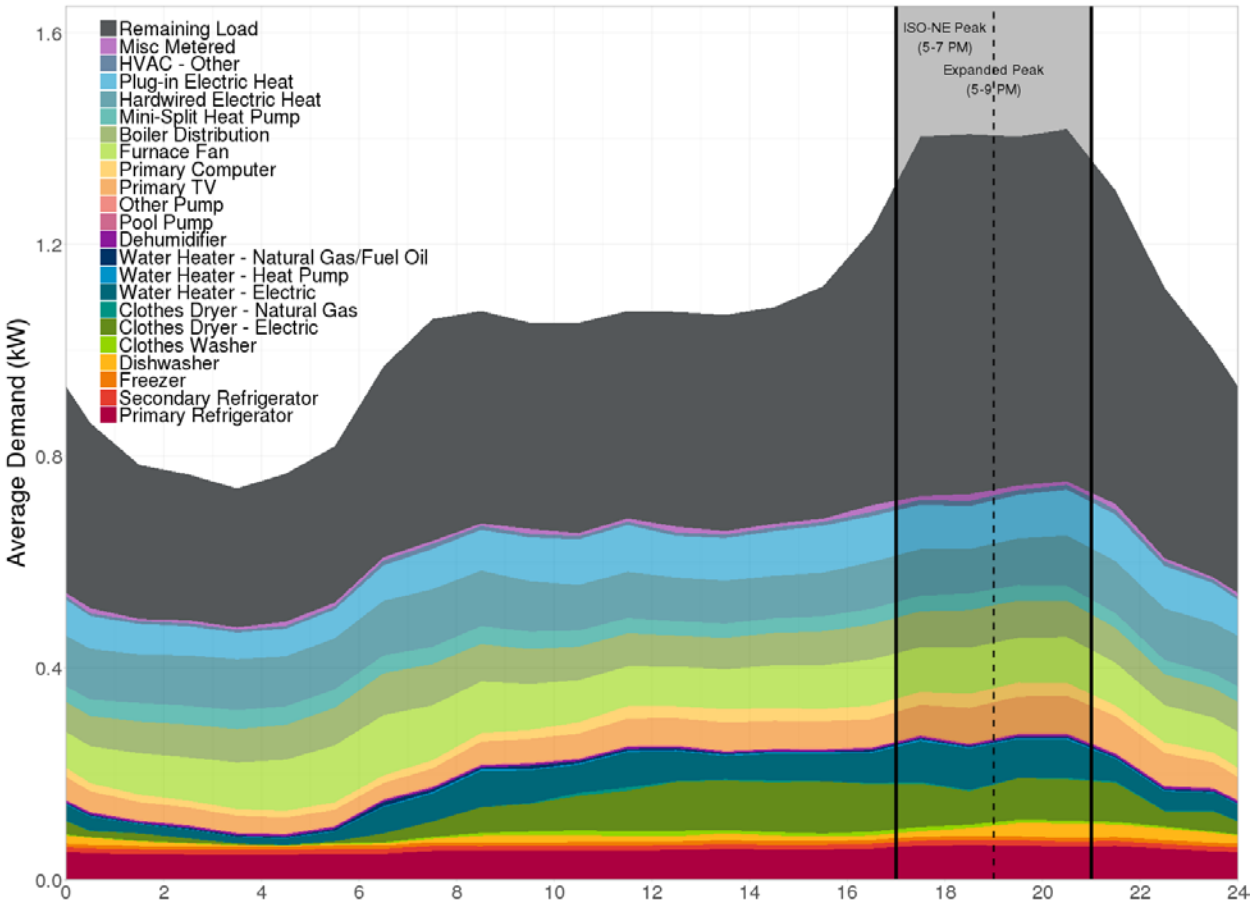


Key Finding: *HVAC and lighting make up the majority of winter peak use.*

[11] The full analysis to incorporate the Northeast Lighting Study results into these metered results will be available in the next report which will cover a full year of metered data. This report will be delivered in May/June 2018.

Figure 6 shows the load shapes of all metered end uses.

Figure 6. Winter Peak Day End Use Load Shapes with Peak Periods Highlighted



Key Finding: *When the major end uses are disaggregated further, no single HVAC end use dominates winter peak demand, but the HVAC category as a whole could present significant savings opportunities.*

Figure 7 and Figure 8 show the end use ISO-NE winter peak demand for homes with the end use, and averaged across all homes. Figure 9 and Figure 10 show the peak demand for high users of each end use, which is much higher than the average for many end uses, and the fraction of homes with the end use who consume more than a given threshold (0.2 kW) during peak.

Figure 7. ISO-NE Winter Peak Demand for Homes with End Use

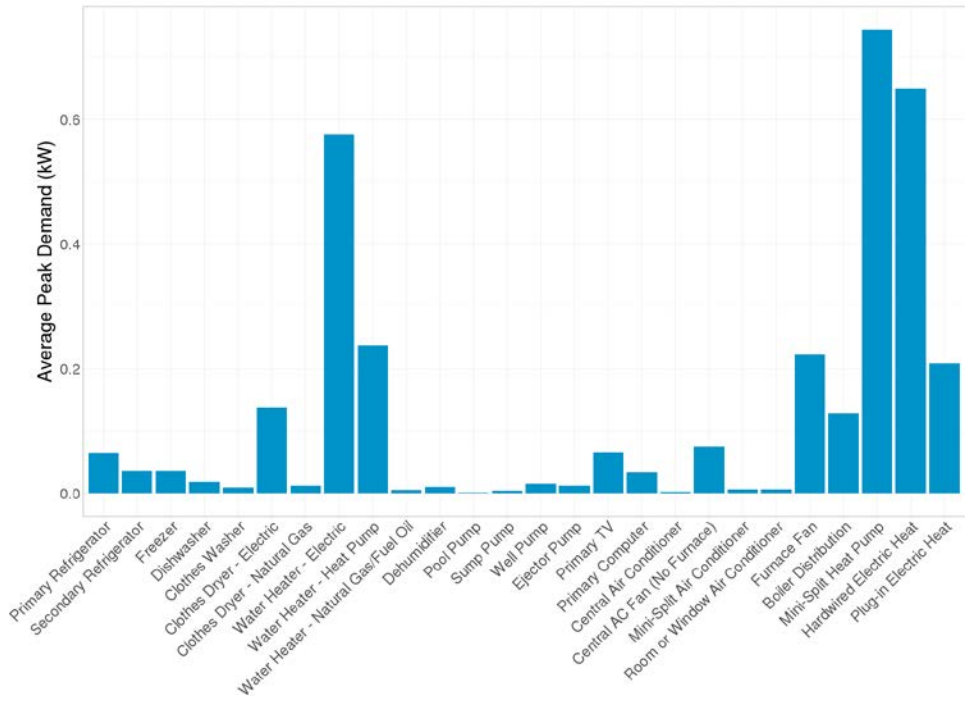


Figure 8. ISO-NE Winter Peak Demand for Population

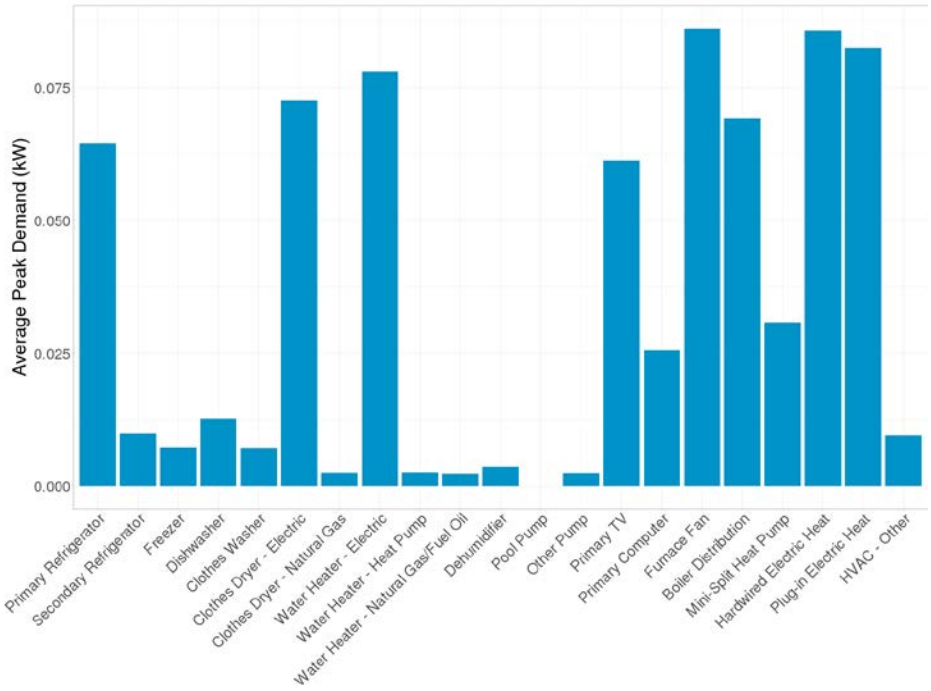


Figure 9. ISO-NE Winter Peak Demand for Top 25% of Users of Each Metered End Use

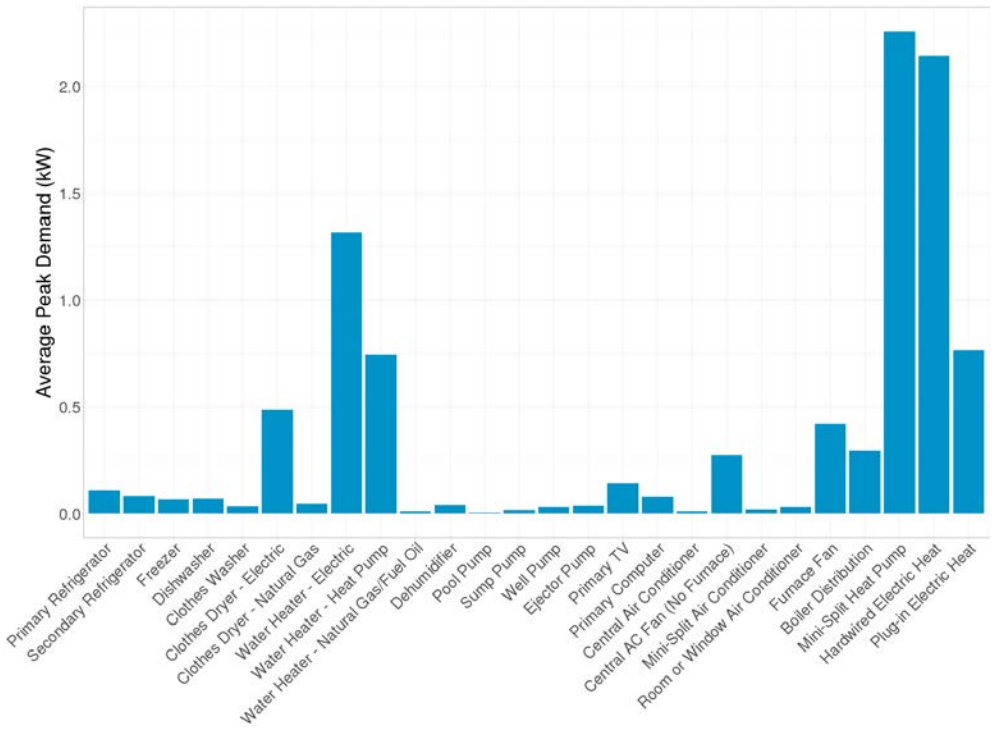


Figure 10. Proportion of Homes with Average ISO-NE Winter Peak Demand Greater than 0.2 kW for Each Measured End Use

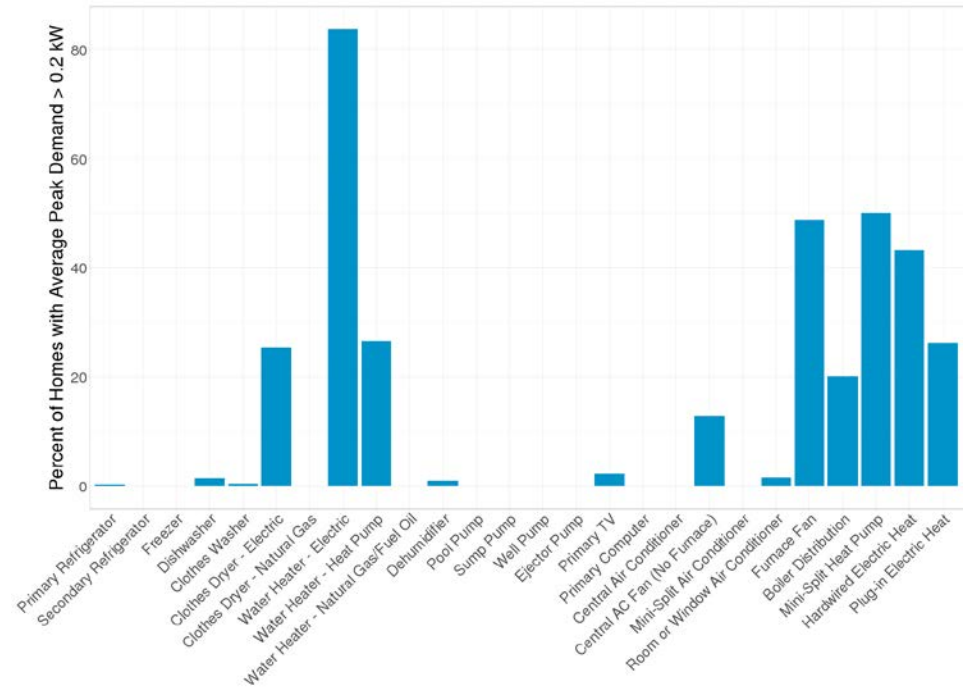


Figure 11 illustrates the average winter peak demand varying by building type, number of occupants, occupancy type, and weekday occupancy. As expected, the greatest opportunity for peak demand savings continues to be HVAC end uses in owned, single family homes with multiple occupants.

Figure 11. Average Winter ISO-NE Peak Demand by End Use Category and Building/Occupancy Demographics

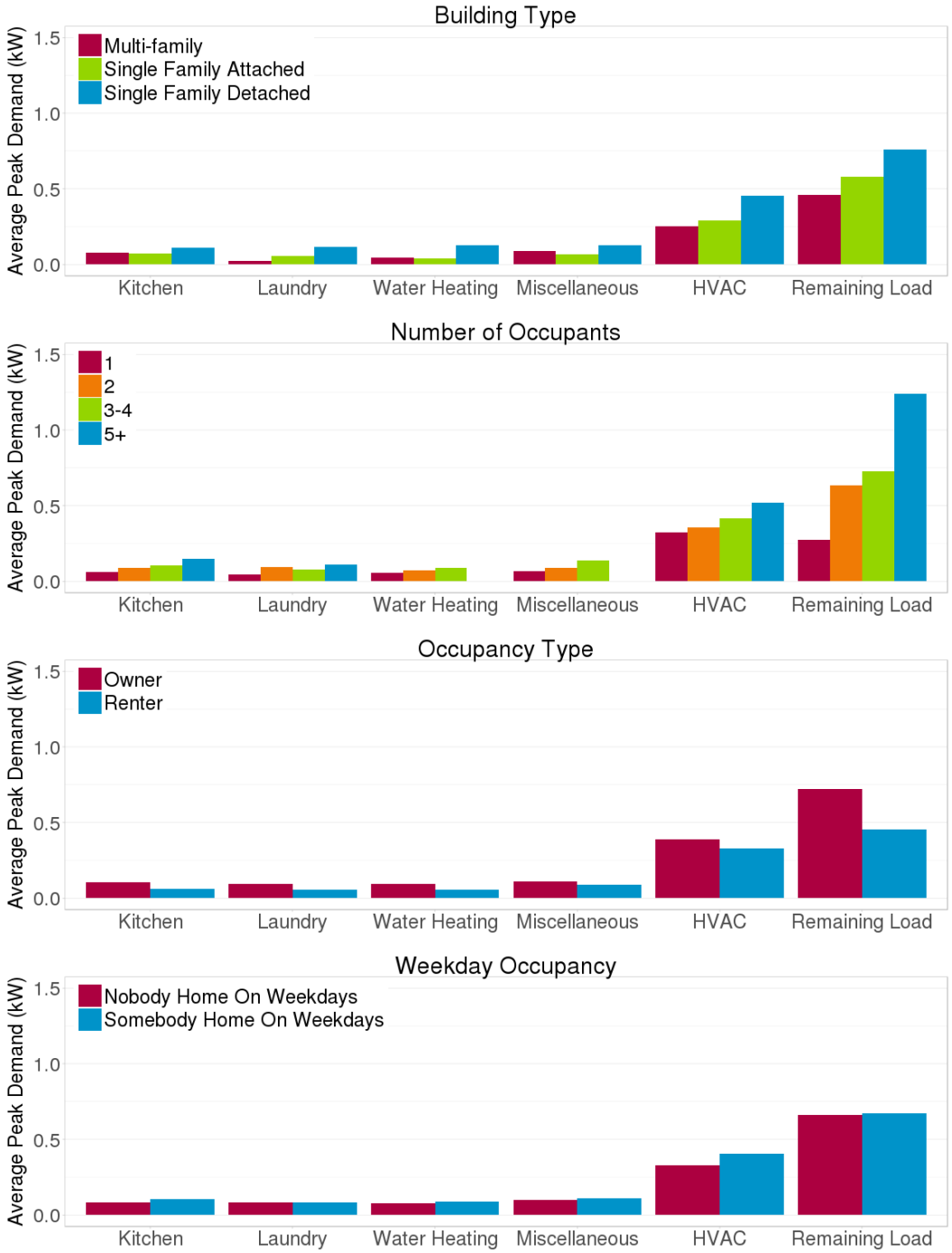


Table 3. Winter Peak Demand by End Use

End Use Category	End Use	Saturation Across MA Homes [A]	ISO-NE Peak Demand for Homes with End Use (kW) [B]	Extended Peak Demand Per Home (kW) [C]	Average Population ISO-NE Peak Demand (kW) [D = A X B]	Average Population Extended Peak Demand (kW) [E = A X C]	Percent of System Average Res. Peak Load (%) [E/∑E]
Heating, Cooling, and Ventilation	Hardwired Electric Heat	0.13	0.22	0.22	0.086	0.086	6%
	Furnace Fan	0.39	0.65	0.67	0.086	0.089	6%
	Plug-in Electric Heat	0.40	0.21	0.21	0.083	0.084	6%
	Boiler Distribution	0.54	0.13	0.13	0.069	0.069	5%
	Mini-Split Heat Pump	0.041	0.74	0.72	0.031	0.03	2%
	HVAC - Other	N/A	N/A	N/A	0.0095	0.0093	1%
	HVAC Total	**N/A**	**N/A**	**N/A**	**0.36**	**0.37**	**26%**
Water Heating	Water Heater - Electric	0.14	0.58	0.56	0.078	0.076	5%
	Water Heater - Nat. Gas/ Oil	0.40	0.24	0.22	0.0027	0.0025	< 0.5%
	Water Heater – Heat Pump	0.011	0.0057	0.0069	0.0023	0.0028	< 0.5%
	Water Heating Total	**N/A**	**N/A**	**N/A**	**0.083**	**0.081**	**6%**
Kitchen	Primary Refrigerator	0.99	0.065	0.064	0.065	0.064	5%
	Dishwasher	0.69	0.018	0.028	0.013	0.019	1%
	Secondary Refrigerator	0.28	0.036	0.036	0.0099	0.01	1%
	Freezer	0.20	0.036	0.036	0.0072	0.0072	1%
	Kitchen Total	**N/A**	**N/A**	**N/A**	**0.094**	**0.1**	**7%**
Laundry	Clothes Dryer - Electric	0.53	0.14	0.14	0.073	0.075	5%
	Clothes Washer	0.73	0.0098	0.0091	0.0071	0.0066	1%
	Clothes Dryer - Natural Gas	0.21	0.012	0.009	0.0025	0.0019	< 0.5%
	Laundry Total	**N/A**	**N/A**	**N/A**	**0.082**	**0.084**	**6%**
Misc.	Primary TV	0.93	0.066	0.071	0.061	0.065	5%

	Primary Computer	0.76	0.034	0.034	0.025	0.025	2%
	Dehumidifier	0.35	0.01	0.011	0.0037	0.0038	< 0.5%
	Other Pump	N/A	N/A	N/A	0.0024	0.0025	< 0.5%
	Pool Pump	0.06	0.0013	0.0013	7.90E-05	7.90E-05	< 0.5%
	Misc. Metered	N/A	N/A	N/A	0.01	0.0087	1%
	Misc. Total	**N/A**	**N/A**	**N/A**	**0.1**	**0.11**	**8%**
Remaining Load	Unknown	N/A	N/A	N/A	0.68	0.67	48%
All	**Total All End Uses**	N/A	N/A	N/A	1.41	1.41	100%

2.3 End Use Specific Findings

This section provides plots and key findings by end use category for a closer look at how each end use contributes to total energy consumption and peak demand.

2.3.1 Heating, Cooling, and Ventilation End Uses

As shown in Figure 12, during the winter hardwired electric heat and mini-split heat pumps are the two end uses with the highest demand in households where they are present. The hardwired electric heat peak day load shape is surprisingly flat compared to existing electric heat load shapes from other sources.

Figure 12. Peak Day HVAC End Use Load Shapes for Homes with End Use

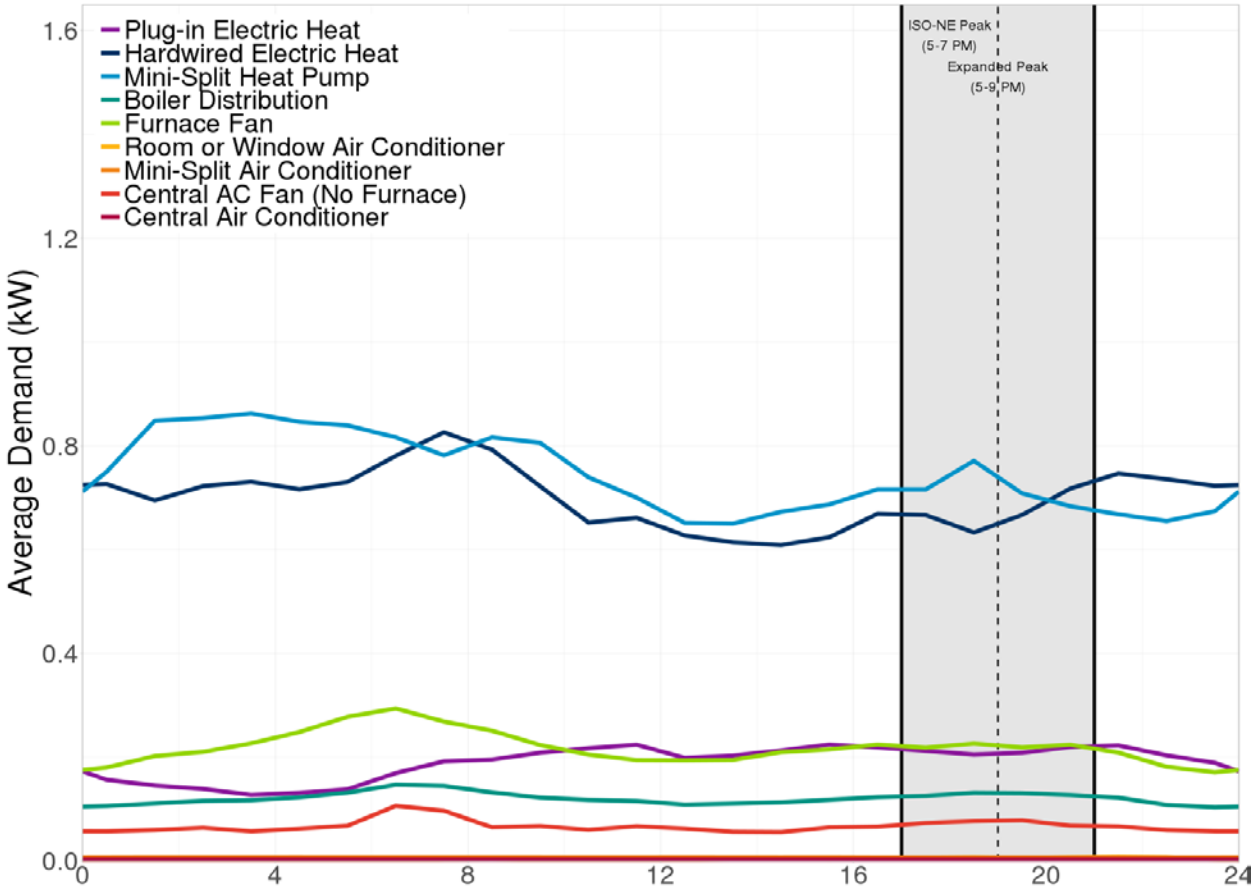
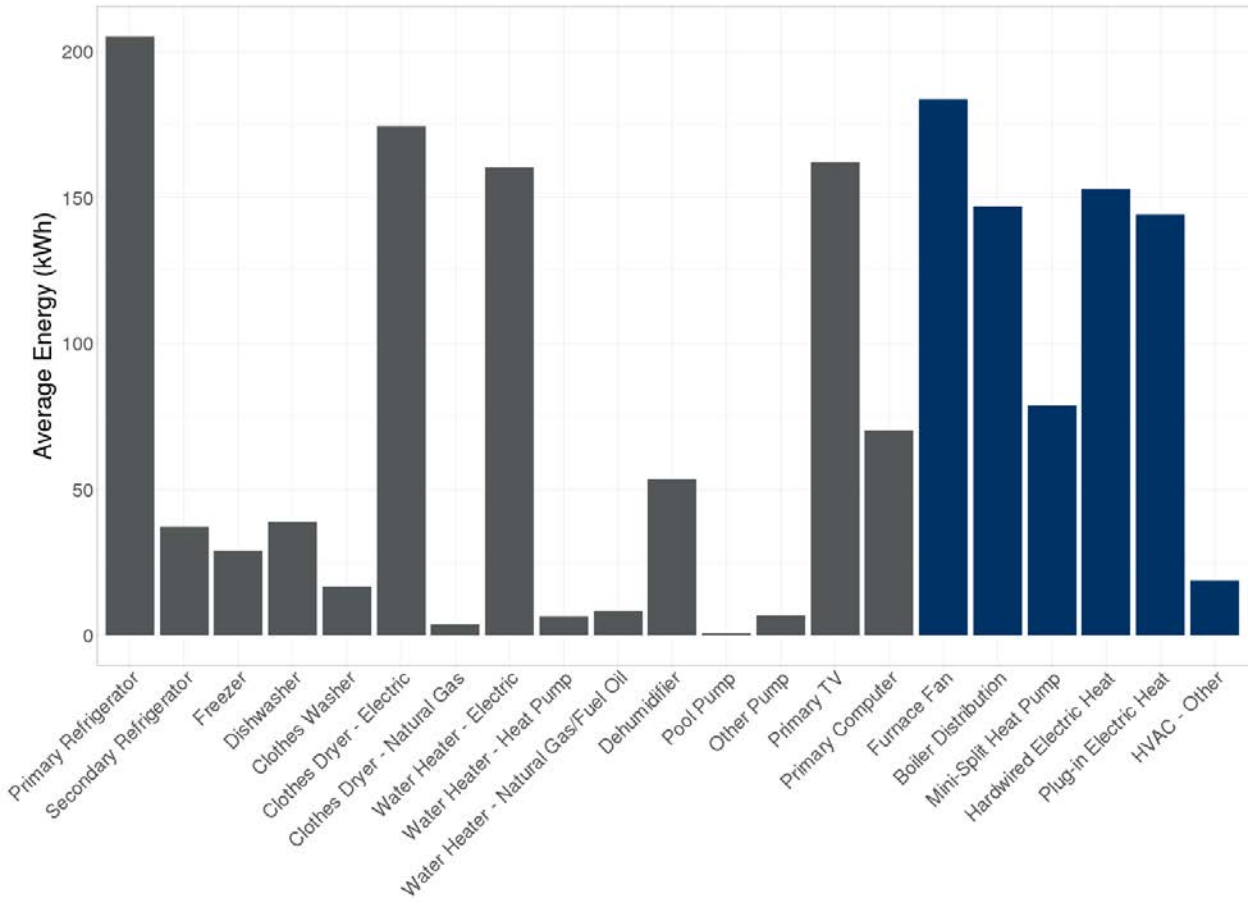


Figure 13 shows that HVAC energy consumption is not dominated by a single end use.

Figure 13. Population Winter End Use Energy Consumption – HVAC End Uses (kWh)

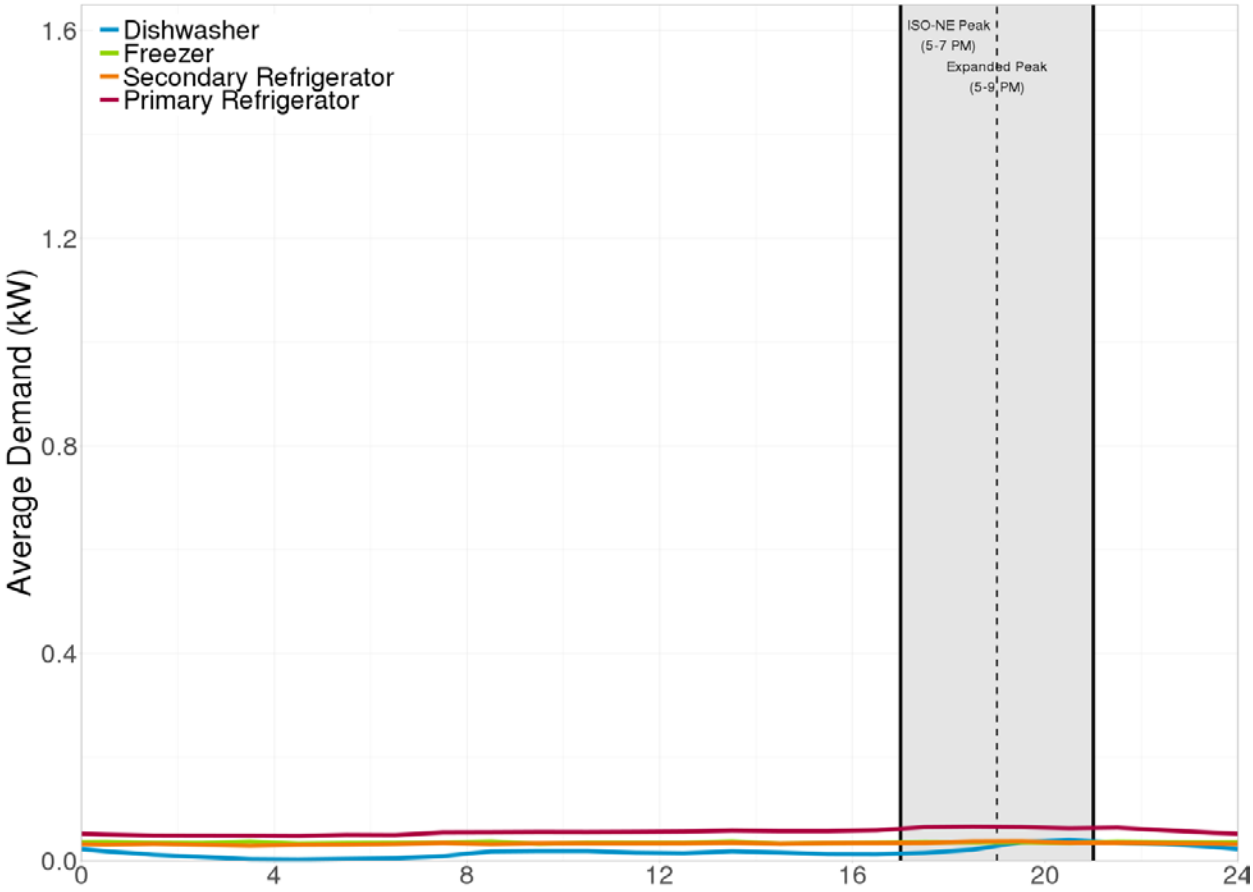


Key Finding: *The saturations of HVAC types are inversely related to their average consumption per household. Therefore, hardwired electric heat, plug-in electric heat, ductless heat pumps, furnace fans, and boiler distribution systems all consume energy within the same order of magnitude, and are equally important as other prevalent non-HVAC end uses.*

2.3.2 Kitchen End Uses

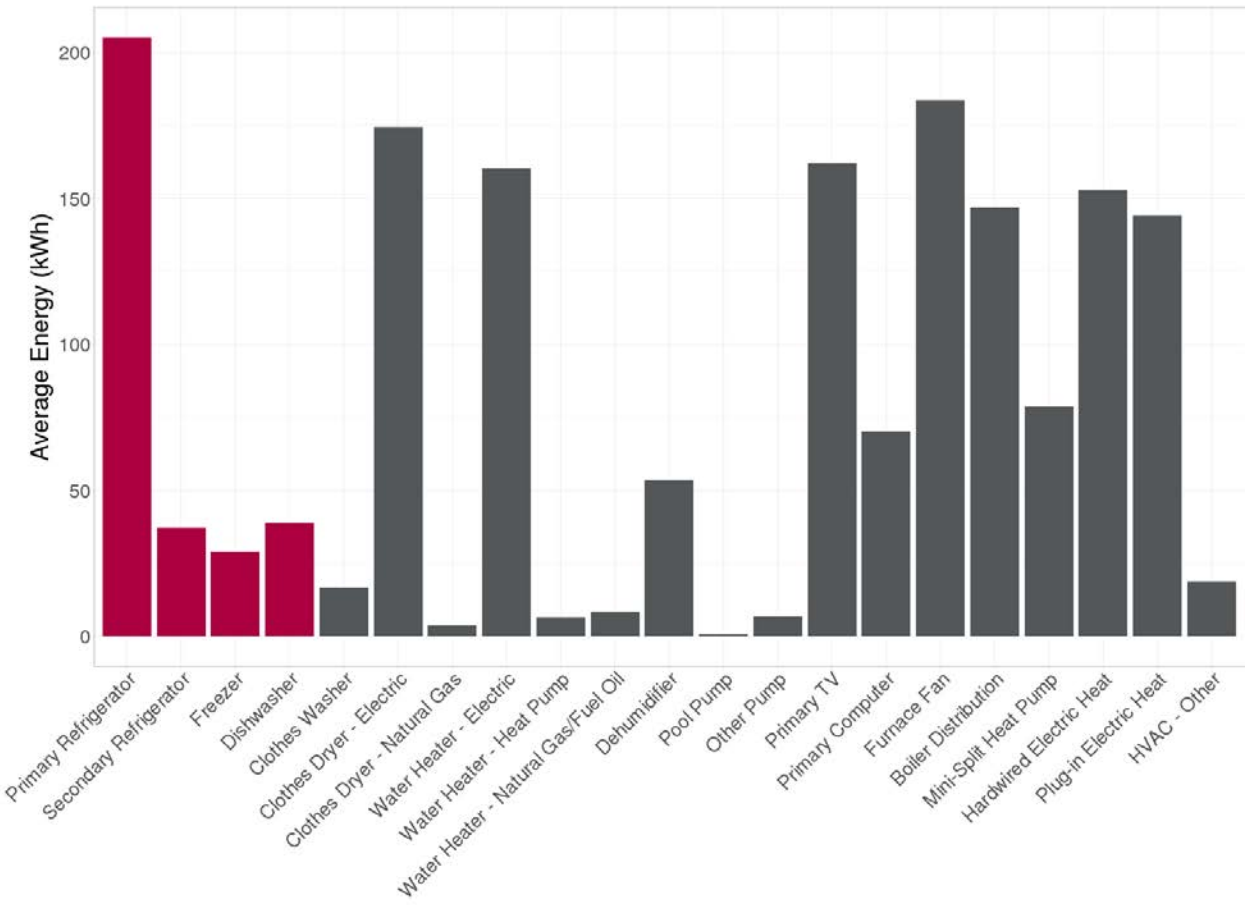
Figure 14 appears to be almost blank, but this is because dishwashers, primary refrigerators, secondary refrigerators, and freezers have low peak demands compared with HVAC end uses and other large peak loads.

Figure 14. Peak Day Kitchen Load Shapes for Homes with End Use



Key Finding: *Kitchen end uses add no significant winter peak load to the system, but refrigerators' energy consumption is considered significant across the entire population because of their high saturation.*

Figure 15. Population Winter End Use Energy Consumption – Kitchen End Uses (kWh)

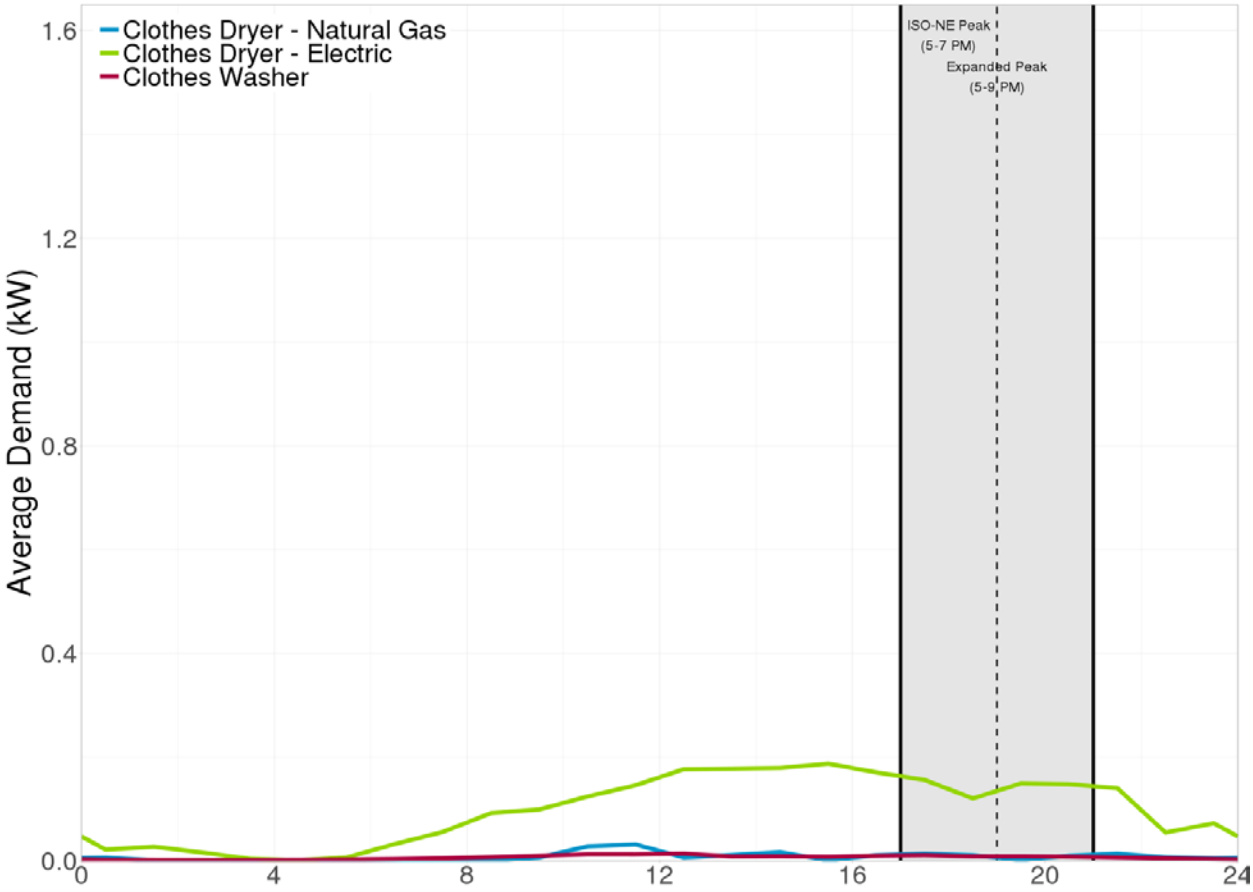


Since refrigerators are in almost all homes and in use at all hours of the day, they show up as the largest winter energy consumer which is shown in Figure 15. Preliminary findings also show some seasonality to refrigerator and freezer energy consumption, with lower consumption in the middle of winter than in the fall months (See monthly energy consumption plots in Appendix C).

2.3.3 Laundry End Uses

Figure 17 shows that while clothes dryer use peaks late in the day on peak days, there is some use throughout the day. The other laundry end uses have near zero demand.

Figure 16. Winter Peak Day Laundry Load Shapes for Homes with End Use



Key Finding: *Some clothes dryers are used throughout the day, including during evening peak.*

Figure 17. Population End Use Winter Energy Consumption – Laundry End Uses (kWh)

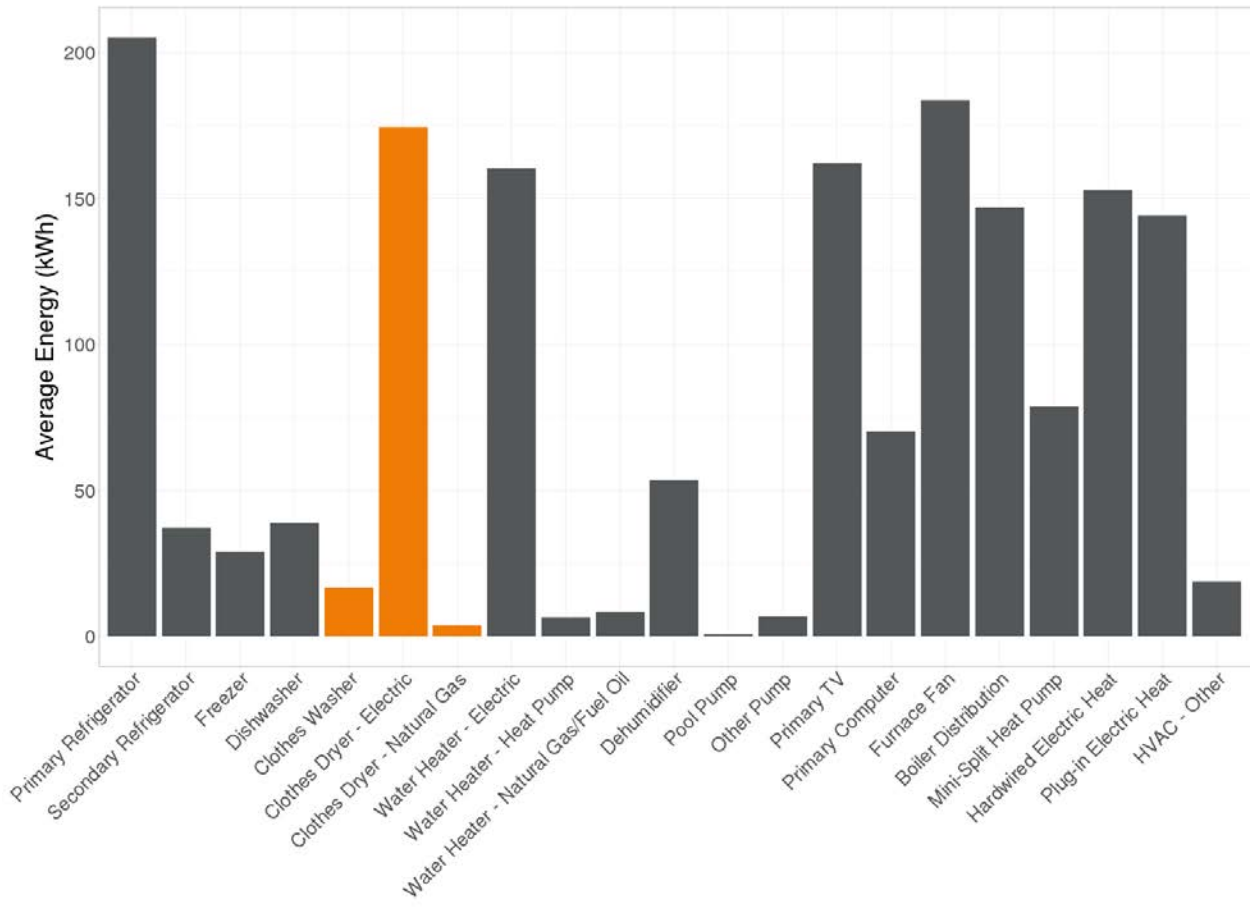
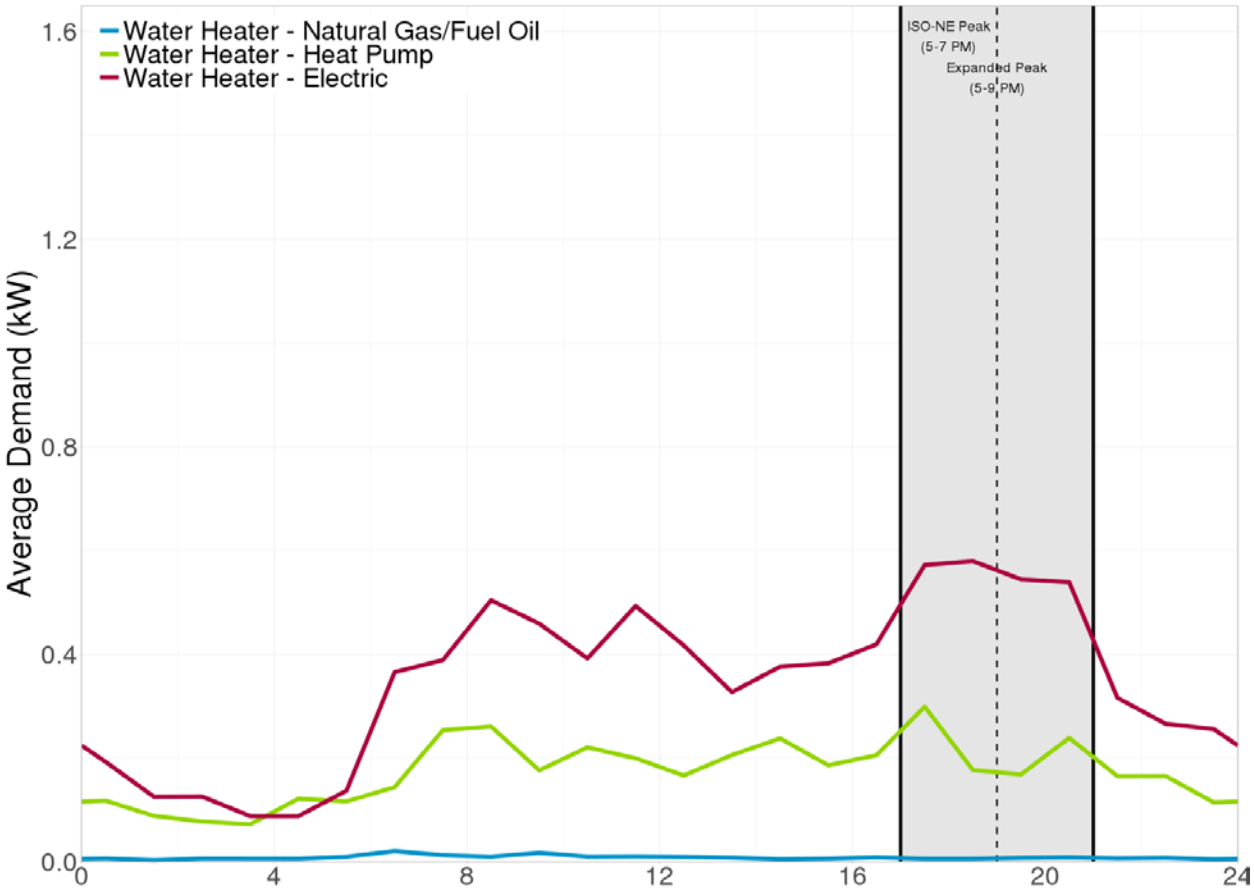


Figure 17 compares laundry end use consumption to energy consumption for other end uses. While clothes dryers have significant winter energy consumption (third largest of all end uses) and clothes washers appear to be low consumers, the energy saved by high efficiency clothes washers shows up primarily as reduced clothes dryer energy consumption and secondarily as reduced water heating consumption. Therefore, the savings potential for clothes dryers should be considered in conjunction with high efficiency clothes washers.

2.3.4 Water Heating End Uses

The study included both regular electric water heaters and an oversample of heat pump water heaters. As shown in Figure 18, the winter peak day load shapes for water heating have a modest double hump, with an initial peak in the morning followed by a second peak in the evening. The shape of heat pump water heaters is based on a relatively small sample of 30 early adopters of the technology, which is indicative of how people use heat pump water heaters today, but may not be representative of long-term adopters' consumption. Overall, heat pump water heaters appear to have demands that are about half of regular water heaters, which roughly corroborates the engineering savings estimates. Because of the small sample, it may be more appropriate to apply the overall water heating load shape to use in calculating peak demand impacts from heat pump water heaters.

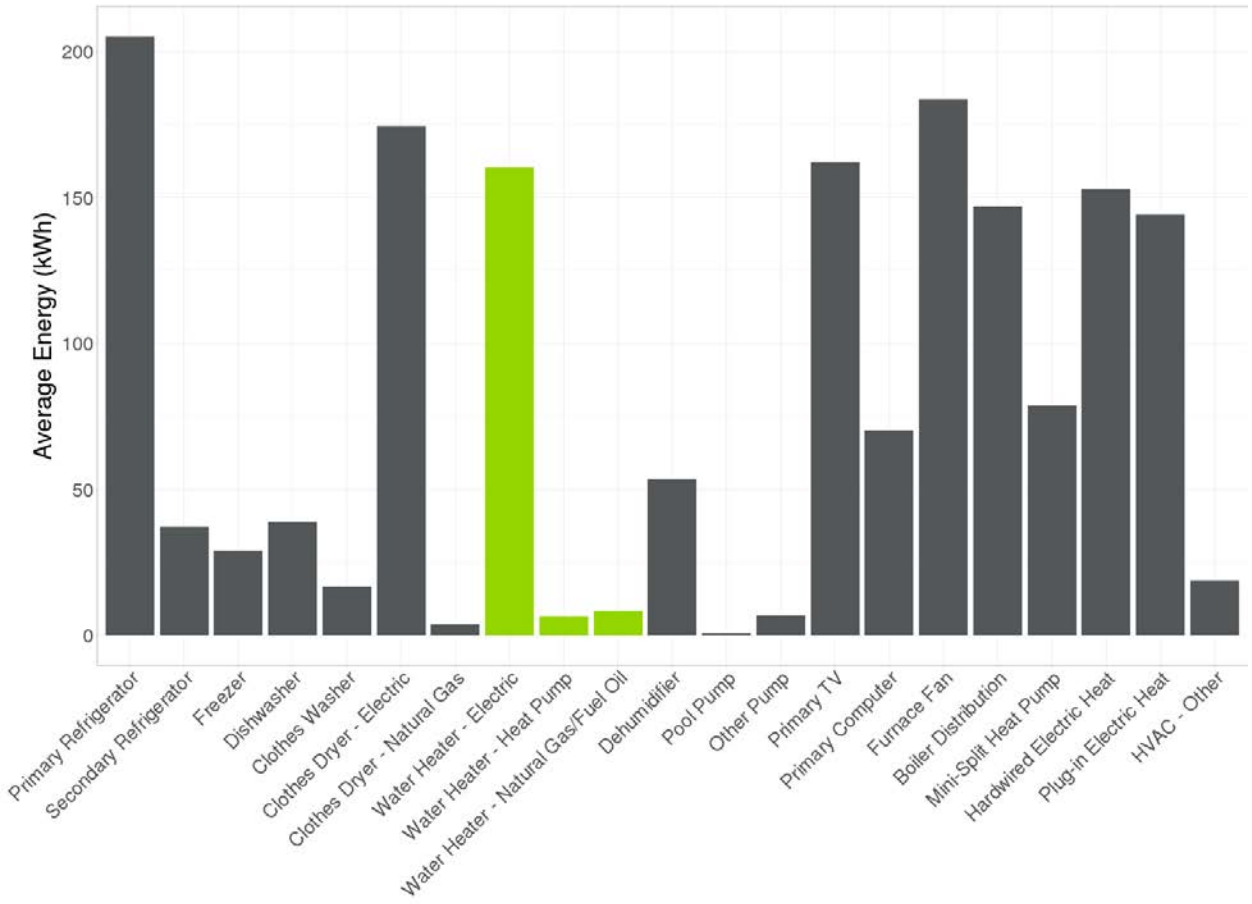
Figure 18. Winter Peak Day Water Heating Load Shapes for Homes with End Use



Key Finding: *Like the cooling season, heat pump water heaters consume about half of the energy and peak demand of regular electric water heaters during the winter months, providing one of the best opportunities for significant reductions in winter peak demand.*

Results from this study, presented in Figure 18 and Figure 19, corroborate model estimates that show there is significant seasonality to water heating consumption, with higher consumption recorded in the winter and lower consumption in the summer. This is consistent with modeled loads using the mains temperature relationship from Christensen and Burch.[12] Over time, electric water heating may also become more important as people transition away from using oil boilers to supply space and water heating needs.

Figure 19. Population End Use Winter Energy Consumption – Water Heating End Uses (kWh)

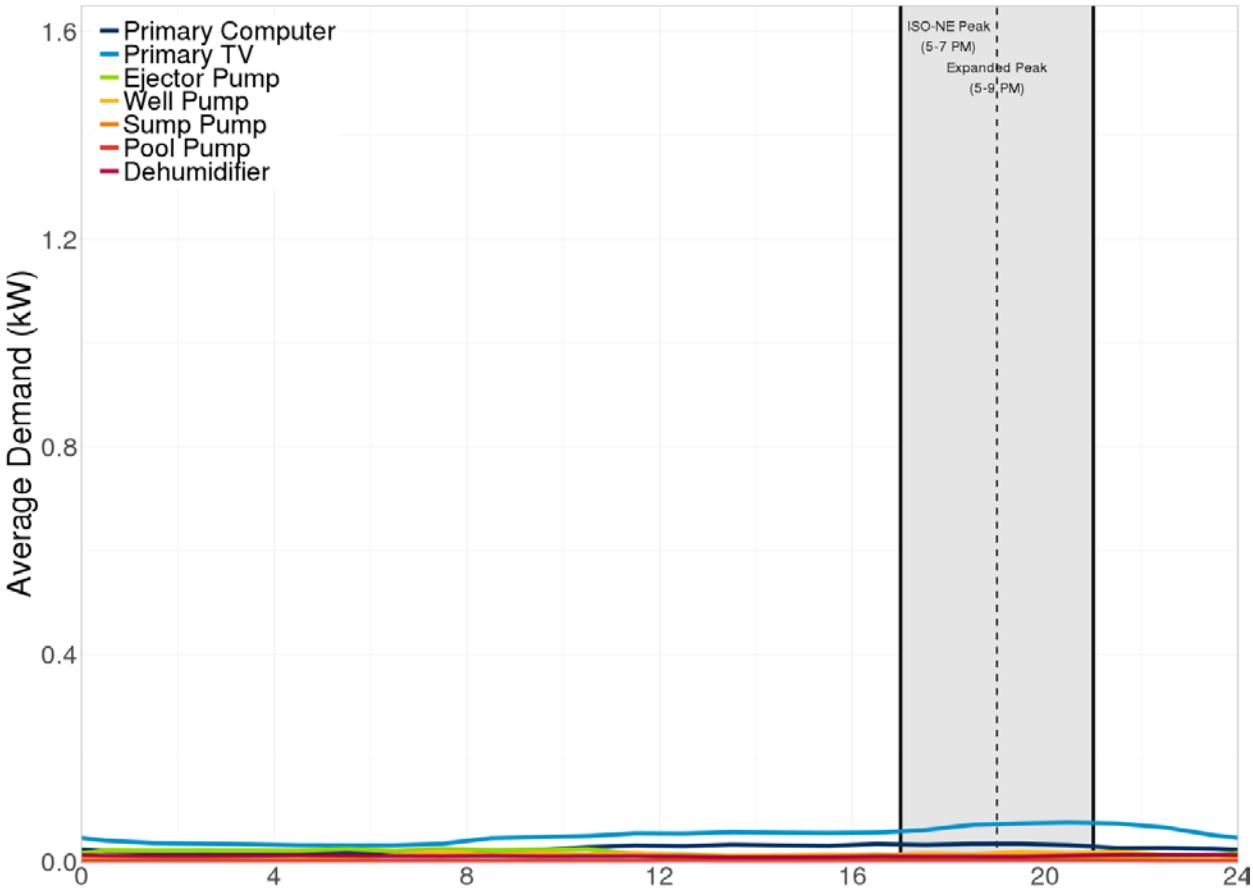


[12] Jay Burch and Craig Christensen, "Towards Development of an Algorithm for Mains Water Temperature." (paper presented at the ASES Annual Conference, Cleveland, Ohio, 2007).

2.3.5 Miscellaneous End Uses

The study targeted a handful of miscellaneous end uses for metering, including primary TV and accessories, primary computer and accessories, pool pumps, dehumidifiers, and a variety of other pumps. None of these end uses contribute significantly to winter peak load.

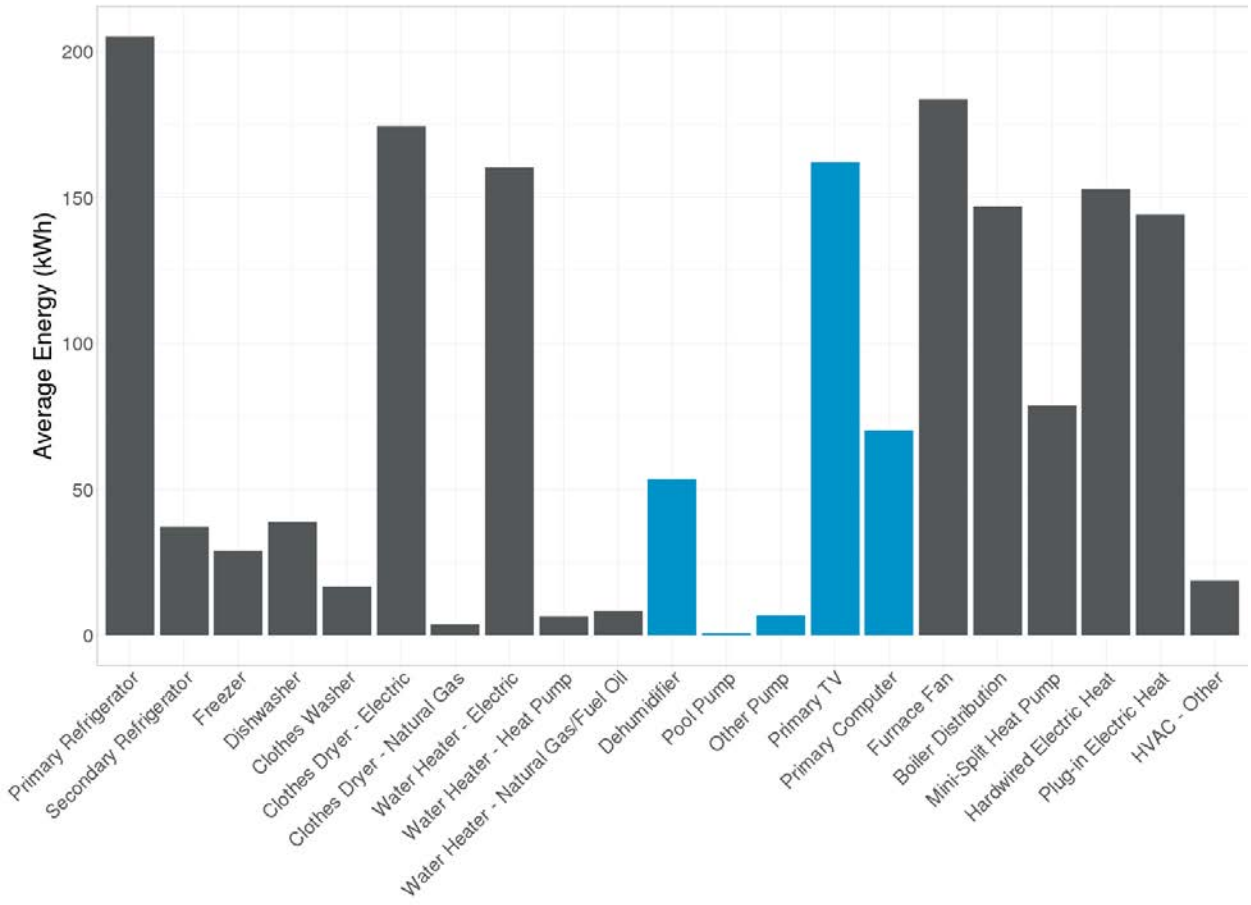
Figure 20. Winter Peak Day Miscellaneous Load Shapes for Homes with End Use



Key Finding: *None of the miscellaneous end uses contribute significantly to winter peaks.*

Of the miscellaneous end uses, primary TVs and primary computers have the most significant winter energy consumption (Figure 21). Dehumidifiers contribute modestly to winter energy consumption. None of the metered pumps (including pool pumps, sump pumps, and well pumps) use much energy in the winter in Massachusetts.

Figure 21. Population End Use Winter Energy Consumption – Miscellaneous End Uses (kWh)



Key Finding: *Primary TVs and accessories consume 6% of residential winter electricity.*

3. CONCLUSIONS AND CONSIDERATIONS

Conclusion 1: Based on initial analysis of lighting data, lighting is likely the end use with the largest contribution to total winter consumption and winter peak.

Conclusion 2: Based on Conclusion 1 above, further improvements in the installed lighting efficiency and controls, either induced by programs or the overall market, will cause significant reductions in peak loads.

Depending on the discount rate assumed and the final results of the potential studies currently being conducted by the PAs, there may remain significant opportunities for programs to cost-effectively reduce energy and peak consumption by inducing the early retirement of incandescent lamps and installation of lighting controls. Particularly where individuals are waiting for infrequently-used lamps to burn out before replacing them, there are significant lifetime savings available in replacing them early. Similarly, networked/connected LEDs offer additional energy and load shifting potential.

Conclusion 3: Electric resistance heat has a surprisingly flat hourly load shape on peak days, more similar to a refrigerator than an air conditioner on a peak day.

Conclusion 4: Electric resistance heating consumption is highly variable. The top 25% of households with electric resistance heat presently consume approximately ten times as much as the median.

Based on conclusions 3 and 4, it may be difficult to generate HVAC peak demand or energy savings with program interventions. Targeting high users would help increase savings by a large amount. A bill-based electric resistance heating targeting algorithm could be developed and tested using this data.

Conclusion 5: Electric water heaters offer a significant opportunity for winter peak demand savings, the largest non-HVAC opportunity.

If the PAs are looking for opportunities to reduce winter peak demand, they should consider electric water heater demand response opportunities and heat pump water heater upgrades in homes with non-electric heat.

APPENDIX A. METHODS

A.1 Online Survey

The online survey was distributed via postcard to 200,300 Massachusetts residents to achieve 6,901 completes. Postcards were mailed to utility account addresses with an invitation to participate in the online survey and a promise of a $10 gift card or check for participating. The invitation postcard also indicated that there would be another opportunity to participate in the metering study to earn $250 more. The primary goal of the survey questions was to understand end use saturation and penetration. The secondary goals of the survey questions were to understand residential customers' motivations for how they use energy and to understand where energy efficiency opportunities exist. Another explicit goal of the survey was to serve as a population frame for the onsite data collection effort.

The online survey was deployed in a modular way so not all survey recipients were asked to respond to all questions, but rather, respondents answered questions about two of the end uses that they have indicated are present in their residence. This allowed the evaluation team to receive an adequate number of detailed survey modules while reducing the burden to the participant. The median survey response took 24 minutes. Bellomy Research programmed and administered the survey and managed the data collection process. The team thoroughly tested the final survey before implementing.

The survey asked questions about the following general areas:

- Premise occupant demographics such as number of occupants, age, work status, income, and homeowner versus renter
- Basic building characteristics such as building type (single or multifamily), age, window type, time since last significant renovation, and recent upgrades
- Presence and basic type of major end uses and appliances including all those listed in Table 1.
- Detailed building characteristics (subset of homes with specific responses)
- Detailed appliance characteristics (including usage)

A summary of the survey recruitment effort and the response rate is shown in Table 4. Reminder postcards were used to boost the representativeness of the sample by increasing the response rate of contacted residents.

Table 4. Survey Recruitment Summary

Wave	Sampling Type	Residents Contacted	Postcards Sent	Complete Responses	Response Rate Per Resident
Pre-test	Random	1,000	1,000	62	6.2%
Wave 1	Random	50,000	150,000	3,364	6.7%
Wave 2	Random	30,000	60,000	978	3.3%
Wave 3	Random	38,000	76,000	1,231	3.2%
Wave 4	Targeted	73,000	73,000	1,038	1.4%
Oversample	Random	8,300	16,600	228	2.7%
Total		**200,300**	**376,600**	**6,901**	**3.4%**

Responses from the online survey informed the load shapes in the following ways:

- The online survey respondents formed the population frame from which the metered sites were sampled.

- The saturations calculated from the online survey responses and onsite visits were used to scale the load shapes to the population. More information about this process can be found in Appendix A.4, “Data Analysis.”
- The binning variables used in the load shape calculations were determined through the online survey responses.
- Onsite end use targets were created based on saturations from online survey responses adjusted for onsite findings.

A.2 Onsite Sampling

The completed responses from the online survey served as the population frame from which the onsite sample was drawn. Having detailed information about each respondent’s home and appliances allowed the team to thoughtfully select a sample capturing several different dimensions of the Massachusetts residential population that will help meet the objectives of the research.

The team used the following proportional quotas to ensure representativeness was maintained in the onsite sample:

- Occupant type: owner-occupied vs. renter-occupied
- Program interaction: previous program participation vs. no previous program participation
- Building type: single family detached vs. single family attached vs. multifamily
- Heating type: gas heat only vs. electric heat present vs. other heat
- Income: low income vs. non-low income
- Electric PA
- Gas PA
- Language spoken at home: English vs. language other than English
- Presence of end use

Navigant’s initial goal for load shapes was to achieve results at the 90% confidence level with relative precisions ranging from 10% to 30% depending on the frequency of occurrence of the end use in the population and the interests of stakeholders in achieving various levels of rigor. Navigant found that data for some housing types and end uses was collected at a high rate in the survey data, while others that may be of interest to the PAs occurred infrequently. Therefore, Navigant implemented oversamples for certain end uses to ensure that sufficient data was collected to produce statistically significant findings at the population level. The oversampled end uses were hardwired electric heat, plug-in space heater/fireplace, electric hot water heaters, heat pump water heaters, and pool pumps.

Table 5 shows Navigant’s final sample for each end use of interest, including the targeted values on which the sample was designed. The precision values in the third through fifth columns of the table are the targeted relative precisions at 90% confidence based on the total number of sites in the last column, which includes the oversampled sites for the five end uses that have been flagged. Some end uses, including ground source heat pumps, tankless water heaters, aquaria, large battery chargers, well pumps, booster pumps, and electric vehicles have been flagged as explicitly having no specific precision target due to the expense required to achieve the target. The team metered these end uses when they showed up in the core sample, but did not structure the sample to target them. Only anecdotal information from a handful of sites is likely to be derived from this study for these end uses, but the team analyzed these results if there were more than five sites with any given end use.

Table 5. Targeted Sampling Assumptions and Achieved Sample

End Use	Assumed Saturation	Targeted End Use Precision - Energy	Targeted End Use Precision – Residential Peak	Targeted End Use Precision – ISO-NE Peak	Number of Core Sample Sites*	Targeted Number of Oversample Sites	Targeted Total Number of Sites
Central AC/Heat Pump	29%	9.0%	9.5%	6.9%	108	0	108
Room AC	64%	18.4%	23.7%	25.6%	142	0	142
Ground Source Heat Pump	1%	95.2%	100.6%	60.4%	3	0	3
Other Electric Heat	13%	20.1%	22.3%	19.8%	52	26	78
Space Heaters/Plug-in Fireplaces	39%	15.0%	36.8%	28.6%	112	11	123
Boiler Circulator Pump	51%	6.6%	10.2%	4.4%	156	0	156
Other Fuel Furnace Fan	53%	8.1%	2.4%	1.7%	104	0	104
Dishwasher	71%	8.4%	20.5%	22.1%	240	0	240
Freezer	13%	8.5%	6.6%	6.1%	66	0	66
Refrigerator	100%	3.0%	3.1%	2.1%	300	0	300
Second Refrigerator	28%	10.5%	9.7%	7.4%	86	0	86
Hot Water Heater	15%	9.8%	12.0%	11.7%	42	3	45
Tankless Hot Water Heater	0.6%	186.1%	289.8%	202.6%	2	0	2
Heat Pump Water Heater	2%	13.0%	20.3%	22.4%	3	28	31
Washer	86%	7.0%	22.1%	19.6%	262	0	262
Electric Dryer	68%	5.5%	45.1%	14.0%	195	0	195
Dehumidifier	50%	12.7%	12.8%	9.1%	116	0	116
Aquarium	2%	41.1%	41.1%	30.1%	6	0	6
Golf Cart/Large Battery Charger	5%	45.5%	45.5%	34.7%	15	0	15
Well Pump	12%	48.6%	51.8%	35.2%	36	0	36
Sump Pump	30%	36.6%	37.4%	28.7%	44	0	44
Booster Pump	5%	36.3%	2.9%	30.2%	15	0	15
Pool Pump	10%	18.2%	19.1%	15.6%	21	7	28
EV Charger	0.4%	N/A	N/A	N/A	1	0	1
Total					**300**	**76**	**376**

* The sum of core sampled sites is greater than the total because the team will collect data for more than one end use from each site.

A.3 Onsite Metering

Navigant field technicians installed metering equipment on all applicable energy consuming equipment to determine end use load consumption and load shape at customer homes. The full list of metered equipment and end uses of interest in this study are in Table 1.

Navigant installed two types of meters in customer homes:

1. **eGauge:** An energy monitoring system installed in residential electric panels[13]
2. **Onset UX-120 Plug Load Meters:** A meter installed directly between the end use equipment and the power outlet[14]

The eGuage and Onset meter setups are shown in Figure 22 and Figure 23.

Figure 22. eGauge Energy Metering Setup in Customer Homes

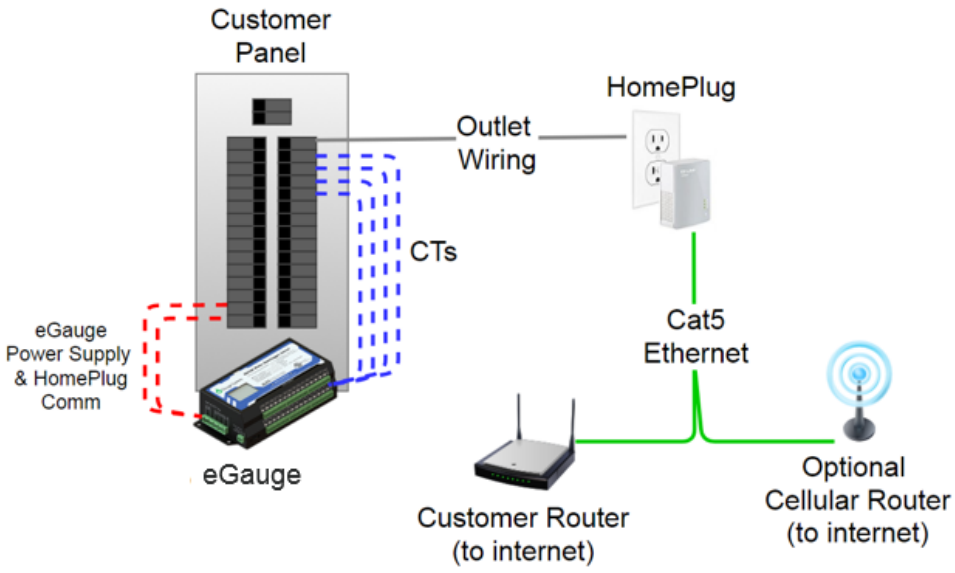


Figure 23. Onset Plug Load Logger Used in Customer Homes

Navigant field technicians programmed both the eGauge and Onset plug load meters to measure the one-minute power consumption of each metered equipment. The meters were programmed to calculate an average energy consumption value for each minute of recording.

[13] For more information about eGauge meters, refer to http://www.egauge.net/products/EG3010/.
[14] For more information about Onset plug load meters, refer to http://www.onsetcomp.com/products/data-loggers/ux120-018.

For all metered equipment, Navigant technicians determined the optimal metering device to use based on several factors, including whether the equipment was installed on a dedicated circuit, if the power outlet was accessible, and customer preference. Whenever possible, Navigant used the eGauge to meter the equipment as it is able to connect remotely to secure eGauge proxy servers, allowing the analysis team to access the data in real time for analysis and quality control. To establish communication between the eGauge and the proxy server, Navigant utilized a Homeplug device, which transmits the eGauge data from the customer's electric panel to a router through powerline communication technology. Navigant used either the customer's personal internet router or a cellular modem/router to securely transmit the metered data to the eGauge servers. Throughout the metering period, Navigant monitored the eGauges remotely on a daily basis to ensure they maintain internet connection and high data quality.

The eGauge metering setup is not appropriate for equipment that are mobile or are not on dedicated electrical circuits, such as space heaters, room air conditioners, and primary televisions. For these equipment, Navigant used the Onset plug load logger, installing it directly between the equipment of interest and the electrical outlet. Navigant secured the meter to the appliance to ensure that it stayed with the appliance of interest, not at the outlet.

Navigant's meter installation period occurred between March and June 2017. Navigant revisited 319 sites in the fall of 2017 to download metered data from the Onset plug load loggers, install meters on newly purchased equipment, and collect characterization data on the equipment if applicable. The resulting metered period for each logged equipment spanned 3-8 months for this phase of the analysis.

In collaboration with NMR, Navigant installed Tier 1 and Tier 2 smart strips on a sample of logged television and computer equipment in the study.[15] These equipment are logged with plug load meters, which will provide data to support deemed savings assumptions for smart strip equipment installed in customer homes. This pre/post metering study will extend through February 2018, at which point Navigant plans to revisit customer homes to download the plug load meter data. The data collected to date on these end uses is included in the results presented in this report.

[15] Both Tier 1 and Tier 2 smart strips contain controlled outlets that switch on and off using smart sensors for the purpose of reducing power consumption of electronics that are not being used. Tier 1 smart strips use current sensing technology. When the control device (such as TV or PC) is turned on, the controlled equipment plugged into the controlled outlets are also turned off. When the control device is turned off, the accompanying equipment also turn off. Tier 2 smart strips use either a motion and/or remote control infrared activity sensor. In this study, the Tier 2 smart strips are only being used for TV and TV-related peripherals. The strip is programmed to turn the equipment off after a period of inactivity, typically one hour. Both smart strip types have a few "Always On" outlets, used for equipment that must remain on at all times due to customer preference, such as internet routers.

A.4 Data Analysis

The saturation and load shape data analysis followed the steps listed below. The saturation data analysis is included because the saturation results played an important role in scaling the load shape results, as explained in Step 3 of the load shape analysis section below.

Saturation Data Analysis

Data from the online portion for 6,901 respondents was cleaned and summarized to generate saturations for all equipment types in residential homes in MA. Saturations were adjusted based on onsite verification, and post-weighted based on the demographics of the survey respondents and the state of MA.

Step 1: Clean data: For values that appeared to be mistakes in the survey responses: quantities greater than 10 for most end uses, or greater than 20 for sink faucets, showers, and gas lighting, values were changed to 1. For heating systems, boilers and furnaces were switched based on the distribution type that was indicated; where radiators were stated, the heating system was changed to boiler, and where ducts were indicated, the system was changed to a furnace. For ductless AC units where surveyees indicated the unit could also provide heat, AC was changed HP.

Step 2: Adjust raw survey data using onsite findings: Onsite data was used to adjust saturations using the ratio of the number of each type of equipment verified onsite to the number of each type of equipment claimed in the survey for each of the 300 sites visited for metering. Onsite adjustment factors were used for all end uses present in at least 10 sites.

Step 3: Apply post weights: In conjunction with the survey responses, a set of weights was developed using demographics information from the American Community Survey (ACS). The demographics selected for weighting results were education level (college degree vs. no college degree), and primary language spoken (English vs. non-English). These two demographics were selected because they had the largest impact on saturation results, they were the two demographics where the survey sample and MA population differed the most, and they were not highly correlated with each other.

Step 4: Calculate saturations: For each 1-D and 2-D combination of the demographic "slicing" variables, separate saturations and quantities were computed for the entire MA population of that demographic. Post weights were normalized for each combination of slicing variables to sum to 1, then the weighted proportion of homes with the end use and weighted mean quantity of per home were calculated for each end use. Absolute precision was also computed at the 90% confidence level.

Load Shape Data Analysis

The load shape analysis consisted of five high level steps. First, 1-minute metered data from eGauge and Onset data loggers connected to all manner of equipment was cleaned and aggregated to create a dataset which has hourly data for each end use at each site. Second, the clean hourly data was summarized across sites for multiple time-periods of interest to compute the energy consumption and demand for sites that have each end use. Finally, the estimates for homes with each end use were combined with saturations to compute consumption and demand of each end use for the MA population.

Step 1: Clean data: For the 1-minute data, eGauge and hobo logger data was checked for reasonableness and usability; systematic checks for incorrect configuration were combined with engineering judgment to determine whether to keep or drop data from each source. Some data was excluded from analysis where eGauges were logging multiple loads on a single register or considerable noise was observed in the data. In some cases, the data from hobo loggers could be subtracted from eGauge registers to isolate an end use, and for some end uses that were not logged because they are never used, data was filled in with zeros.

Step 2: Aggregate to Site, End Use, Hourly Granularity: First, for each logged piece of equipment, 1-minute data was aggregated to hourly data by computing the average kW observed in each hour. Next, hourly unit data was summed into end use totals at each site, for each hour.

> **Adjustments:** For hours where not all units of a given end use were logged, (e.g. only 2 out of 3 room ACs) data was scaled up using the ratio of total units to logged units.

Step 3: Calculate site-level end use load shapes: For each site, end use, and each time period of interest (all days, weekdays, weekends, winter 2017, calendar months, peak days, and peak periods), average kW was computed.

> **Exceptions**: Data was removed where a site and end use combo had less than half of the total hours in the period logged (e.g. for the ISO-NE peak, which covers 16 hours total, only sites with 8 or more hours of data for a given end use were included in the average).

> **Modifications:** Certain end uses were combined to broader categories, and data was summed across end uses to arrive at category (e.g. HVAC) level average kW per period. Specific combinations are provided in the table below. A different set of categories may be appropriate for the winter metering and final results.

Table 6. Combined End Uses for Load Shape Analysis

Category	End Uses Combined
Hardwired Electric Heat	Elec baseboard heat, Elec furnace
HVAC – Misc	Whole house fans, Fireplace blowers, HRVs, Bathroom fan heaters, and Ground source heat pumps
DHW – Gas/Oil	DHW – Gas, DHW – Gas Tankless, DHW – Oil, DHW – Propane
Misc Metered	Pool heaters, Hot tubs, EV chargers, Battery chargers, Booster pumps, Freeze prevention, Fish tanks, Water beds

Step 4: Calculate load shapes for homes with each end use: For each demographic slicing variable, end use, and time period, the average kW across sites was computed. Statistics (standard error and relative precision) were also computed at this level, based on the variation in the site-level results.

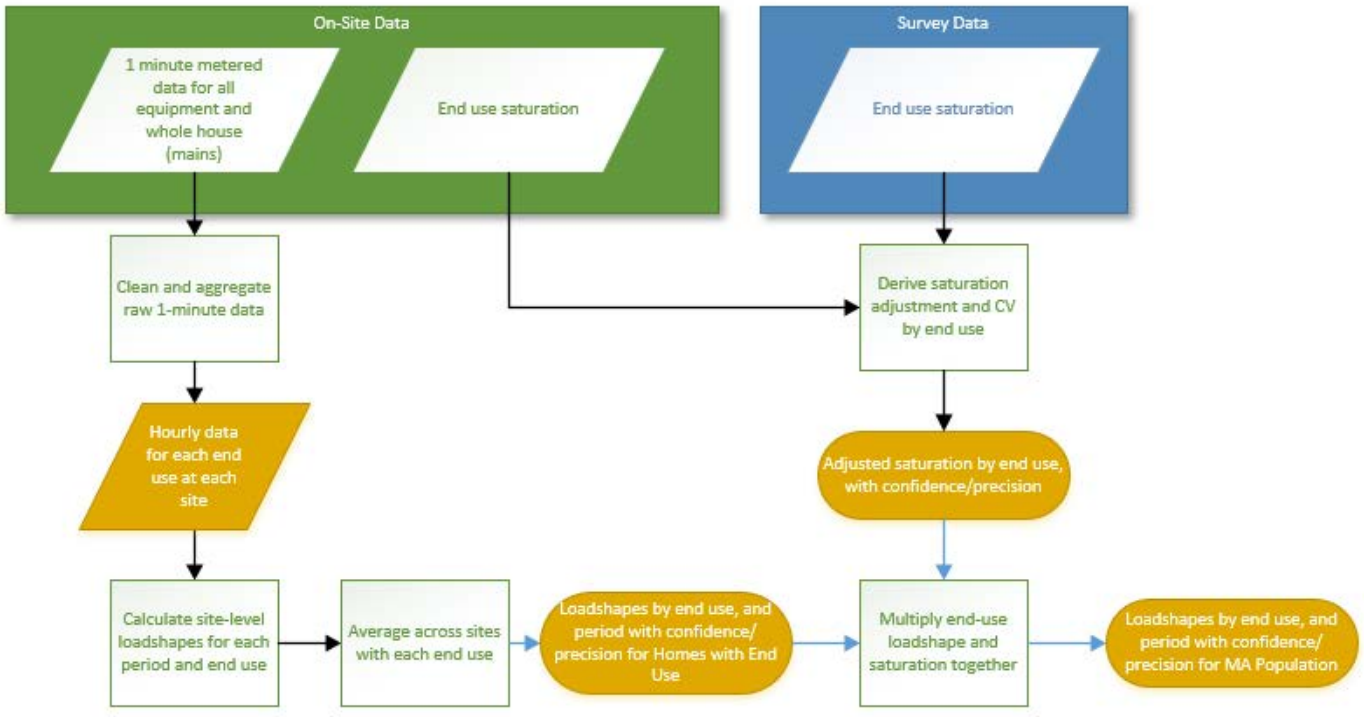
> **Exceptions**: Data was removed for demographic and end use combinations where there was data from less than 5 sites (e.g. for end use XXX and demographic YYY, there were only 4 sites, so no result was computed for that combination).

Step 5: Calculate load shapes for the MA population: The average kW per home, end use, category, and time period from the previous step was multiplied by the corresponding statewide saturation (for each end use and demographic) to compute statewide average kW for each end use, across all homes.

> **Modifications**: Some end uses like Air Handling Units were metered onsite but were not explicitly included in the survey and did not have saturations in the July 17 deliverable, saturations were newly computed for these end uses. The "remaining load" load shape was computed by subtracting all metered end use load shapes from whole home average consumption.

Figure 24 is a schematic representation of the saturation and load shapes analysis.

Figure 24. Saturation and Load Shape Analysis Map



APPENDIX B. STATISTICS

The study attained confidence and precision shown in Table 7.

Table 7. Comparison of Actual Relative Precision to Expected Relative Precision

End Use	Targeted Energy Precision	Actual Winter Energy Precision	Targeted End ISO-NE Peak Precision	Actual ISO-NE Peak Precision
Central Air Conditioner	10.10%	53%	9.90%	44%
Room or Window Air Conditioner	15.80%	102%	28.20%	89%
Ground Source Heat Pump	84.30%	N/A	93.60%	N/A
Hardwired Electric Heat	20.50%	33%	77.20%	24%
Plug-in Electric Heat	15.00%	29%	36.80%	23%
Boiler Distribution	6.70%	14%	5.80%	11%
Furnace Fan	6.60%	13%	1.70%	10%
Dishwasher	9.00%	11%	30.10%	26%
Freezer	11.20%	15%	10.40%	12%
Primary Refrigerator	3.00%	5%	2.70%	5%
Secondary Refrigerator	10.70%	19%	9.60%	14%
Water Heater - Electric	6.70%	12%	15.00%	18%
Tankless Water Heater	186.10%	N/A	415.60%	N/A
Water Heater - Heat Pump	13.00%	25%	29.10%	48%
Clothes Washer	7.00%	11%	25.40%	20%
Clothes Dryer - Electric	5.40%	9%	17.60%	18%
Dehumidifier	11.20%	31%	10.30%	51%
Aquarium	41.10%	N/A	41.10%	N/A
Golf Cart/Large Battery Charger	45.50%	N/A	45.50%	N/A
Well Pump	48.60%	28%	45.60%	27%
Sump Pump	25.30%	78%	25.60%	86%
Booster Pump	36.30%	N/A	39.60%	N/A
Pool Pump	18.20%	105%	20.20%	55%
EV Charger	N/A	N/A	N/A	N/A
Primary TV	N/A	18%	N/A	16%
Primary Computer	N/A	37%	N/A	30%

APPENDIX C. SUPPORTING DATA

The supporting data for all end use load shapes are included in the attached spreadsheets. The statistics for each value are also included within the spreadsheets.

Table 8. Appendix C Supporting Documents File Names and Contents

File Name	File Type	Contents
Appendix C-1 Draft Heating Season Results Plots 2018-03-15	PDF	Detailed plots of winter consumption, peak demand, and load shapes by end use and demographic
Appendix C-2 Draft Heating Season All End Use Metered Whole Period Results 2018-03-15	Excel	Total winter consumption and peak demand for each end use and time period with statistics
Appendix C-3-1 Draft Heating Season HVAC Metered Load Shape Results 2018-03-15	Excel	Hourly load shapes by end use, demographics, time period, and day type with statistics
Appendix C-3-1 Draft Heating Season Water Heating Metered Load Shape Results 2018-03-15	Excel	
Appendix C-3-1 Draft Heating Season Kitchen Metered Load Shape Results 2018-03-15	Excel	
Appendix C-3-1 Draft Heating Season Laundry Metered Load Shape Results 2018-03-15	Excel	
Appendix C-3-1 Draft Heating Season Miscellaneous Metered Load Shape Results 2018-03-15	Excel	
Appendix C-3-1 Draft Heating Season Remaining Load Load Shape Results 2018-03-15	Excel	